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THESIS

NUCLEATE POOL BOILING OF R-114 AND R-114/OIL
MIXTURES FROM SINGLE ENHANCED TUBES

by

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Nucleate Pool Boiling of R-114 and R-114/Oil Mixtures
from Single Enhanced Tubes

by

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ABSTRACT

Nucleate pool boiling heat transfer is an integral part of any vapor-compression refrigeration cycle. With a view to improving overall cycle efficiency, the heat transfer performance in the evaporator can be improved by using enhanced boiling surfaces. This thesis looks at the pool boiling characteristics of R-114 (presently used in large shipboard AC systems) from 10 enhanced single copper tubes and compares performance with a smooth copper tube. Since small amounts of oil escape into the refrigerant as it passes through the compressor of a refrigeration system, tests have also been conducted with up to 10% (by weight) of a miscible oil to see what effect this may have on overall evaporator performance.

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NOMENCLATURE

A	area
Ab	tube outside surface area of active boiling section
Ac	cross-sectional area of tube
Cp	specific heat
D	diameter
Di	tube inside diameter
Do	tube outside diameter
D1	diameter at the position of the thermocouple
D2	outer diameter of the boiling tube
g	gravitational acceleration
h	heat-transfer coefficient
hfg	latent heat of vaporization
I	current
Is	current reading by AC Current Sensor
k	thermal conductivity of liquid
kc	thermal conductivity of copper
L	active boiling tube length
Lu	non-boiling length of the test tube
Nu	Nusselt number
p	tube outside wall perimeter
Pr	Prandtl Number
Q	heat-transfer rate from boiling surface
Qf	heat-transfer rate through one nonboiling end
Qh	heat-transfer rate from cartridge heater
q"	heat flux
Ra	Rayleigh number
T	temperature
Tavg	average wall temperature at the thermocouple location
Tc	critical temperature
Tf	film temperature

Tn	temperature of the thermocouple location
Tsat	saturation temperature
Two	outer wall temperature of the boiling test tube
V	voltage across the cartridge heater
Vs	voltage reading by AC-DC true RMS converter
α	thermal diffusivity
β	volumetric thermal expansion coefficient
δ	uncertainty in measurement and calibration
θ	superheat
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density

I. INTRODUCTION

A. BACKGROUND

The United States Navy currently uses R-114 in approximately 950 centrifugal chilled-water air-conditioning plants. Ongoing efforts to reduce the cost and increase the efficiency of these plants have been directed towards the use of enhanced heat-transfer tube surfaces and alternative refrigerants. The choice of alternative refrigerant must be "ozone friendly." A possible "drop in" replacement for R-114 has been identified: R-124. Studies of the boiling performance of R-124 would be complemented well by a baseline of data on R-114.

B. ADVANTAGES OF USING R-114

The use of R-114 in Naval applications has been driven by concerns for both cost and safety. R-114 operates under moderate pressures and has one of the lowest toxicity ratings among all refrigerants. System components are significantly smaller and more lightweight which is desirable for shipboard use and maintenance. While R-11 is widely used in industry, its operating requirements make it unsuitable onboard ship. R-11 operates under vacuum and has a tendency to absorb ambient moisture. This acidic combination of R-11 and moisture attacks tubes and causes corrosion. R-114 is considerably stable to

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heat and may be used with all standard ferrous and non-ferrous metals except zinc, magnesium and aluminum alloys containing appreciable amounts of zinc and magnesium. The thermophysical properties of R-114 are provided in Appendix A.

C.   THESIS OBJECTIVES

Safety requirements for future studies of R-124 necessitated the disassembly and relocation of the single-tube apparatus described in this thesis. Past studies using the apparatus have varied considerably in operating procedure, thus it became desirable to establish a consistent operating procedure in the acquisition of all data on R-114. With the foregoing discussion in mind, the objectives of this thesis were to:

1. Relocate and calibrate the single tube apparatus.

2. Operate the apparatus to produce repeatable data and confirm earlier results.

3. Obtain boiling data for R-114 and R-114/oil mixtures on ten tube surfaces to be used as a database for future studies on enhanced surfaces and alternative "ozone safe" refrigerants.

II. REVIEW OF REFRIGERANT AND REFRIGERANT/OIL POOL BOILING BEHAVIOR

A. NUCLEATE POOL BOILING PERFORMANCE OF PURE R-114

The heat-transfer performance of pure R-114 on a smooth tube in the natural convection region of its boiling curve can be reasonably predicted using well known correlations, Churchill and Chu [Ref. 1] and more recently Churchill and Usagi [Ref. 2]. A lack of complete understanding of the nucleate boiling mechanism makes it more difficult the to predict the performance in the nucleate boiling region. Well known correlations, such as that by Rohsenow [Ref. 1], and more recently, Stephan-Adelsalam [Ref. 3] are approximate and should be compared with experimental data whenever possible.

Many pool-boiling experiments have been carried out on finned tubes (typically 19 to 40 fpi) in pure refrigerants. For various refrigerants, tube material, fin density and system pressure, typical enhancements in the heat transfer coefficient (over smooth tubes values) of up to 3 have been reported, the refrigerants with better wetting characteristics giving the greater enhancement. Interestingly enough, the boiling performance of finned tubes becomes very similar to that of smooth tubes, if the heat flux is recalculated on the basis of total outside wetted surface area (rather than root diameter, which is commonly used).

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Re-entrant cavity surfaces differ from finned surfaces in that they provide a higher density of stable nucleation sites with minimum wall superheat (Yilmaz and Westwater [Ref. 4] Carnavos [Ref. 5], Marto and Lepere [Ref. 6] and Wanniarachchi *et al.* [Refs. 7, 8]). Significant improvements in heat transfer over both finned and smooth tubes have been shown for re-entrant cavity surfaces.

Boiling enhancements were as large as 14.6 and 6.4 for High Flux and Turbo-B tubes, respectively, compared to smooth tube data.

Webb [Ref. 9] stated that the key to the high performance of the re-entrant surfaces can be attributed to three factors: (1) re-entrant cavity within a critical size range, (2) interconnected cavities, and (3) nucleation sites of a re-entrant shape. If the cavities are interconnected, adjacent cavities can activate each other. Re-entrant cavities provide a stable vapor trap, which can remain active at low values of superheat.

During nucleate boiling of R-114 at one atmosphere, Wanniarachchi *et al.* [Refs. 7 and 8] reported data for four enhanced tubes: a porous coated High Flux, Thermoexcel-E, Thermoexcel-HE and a 26 fpi GEWA-T. Enhancements of 9.1, 8.2, 6,8 and 4.4 respectively were obtained at a heat flux of 30 kW/m^2. The enhancement provided by the High Flux tube reduced to 6 at higher fluxes of about 100 kW/m^2, but it still outperformed the other three tubes. At heat fluxes below 18

kW/m^2, both the Thermoexcel tubes performed the best. However, they noted that the uncertainty in the data increased as both superheat and heat flux decreased.

Whereas the majority of pool-boiling experiments use electrically heat tubes, McManus *et al.* [Ref. 10] used hot water to heat both a High Flux and Turbo-B tube in a pool of R-114. The range of heat flux was very limited. However, at a heat flux of 40 Kw/m^2, enhancements of 14.6 and 6.4 respectively, were obtained over smooth tube values.

B. NUCLEATE POOL BOILING PERFORMANCE OF REFRIGERANT-OIL MIXTURES

Most refrigeration systems use hermetically sealed compressors which allow small quantities of oil to escape into the working fluid. This oil tends to collect in the flooded evaporator, giving up to 10% oil in some cases. The nucleate pool boiling mechanism is further complicated when a less volatile component, such as miscible refrigerant oil, is mixed with the refrigerant. Design and modelling rely heavily on accurate experimental data covering a wide range of operating conditions.

Compared with pure refrigerants, there is little data for boiling of refrigerant/oil mixtures from finned surfaces. Chaddock [Ref. 11] gives a thorough summary of such mixtures through 1975. Sauer *et al.* [Ref. 12] report data from 19 fpi copper tube using R-11 with two different oils. For oil

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concentrations less than 3%, their results indicated no difference in boiling heat transfer performance from that of the pure refrigerant. For oil concentrations greater than 5%, significant degradation in performance was shown. They concluded that finned tubes performed best at low wall superheats and that this performance was not impaired by up to 3% oil addition.

Murphy [Ref. 13] carried out experiments on a 26 and 40 fpi tube using R-114/oil mixtures. Similar to Sauer [Ref. 11], no difference in performance was observed for oil concentrations up to 3%. Indeed in some cases, at a higher heat flux of about 100 kW/m^2, a 3% oil concentration showed a small _increase_ in performance over the pure refrigerant case. The mechanism for this improvement is not well understood, but has been found by a number of investigators for both flow and pool boiling. At a 10% oil concentration, both tubes exhibited a 30% degradation in performance versus the pure refrigerant case, which agreed with Sauer's findings.

Wanniarachi _et al._ [Refs. 7, 8] reported the performance of High Flux, Thermoexcel-E, Thermoexcel-HE and GEWA-T tubes in R-114/oil mixtures at one atmosphere. Oil concentrations up to 10% (by weight) were studied. A marked increase in the wall superheat values required for the incipience of nucleate boiling was observed in the presence of oil. Enhancements mentioned previously for pure R-114 were reduced at a 3% oil concentration, to 7.5, 5.5, 5.5 and 3.8 respectively. With 10%

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oil concentrations, further reductions to 5.5, 3.8, 3,8 and 2.9 were observed. At the highest heat fluxes (> 45 kW/m^2) and for oil concentrations greater than 6%, the performance of the High Flux tube degraded at a rate that left the GEWA-T tube as the best performer.

III. DESCRIPTION OF EXPERIMENTAL APPARATUS

A. OVERVIEW OF THE SYSTEM

Wanniarachchi *et al.* [Ref. 7], Murphy [Ref. 13] and Karasabun [Ref. 14] provide complete details of the original apparatus used in previous studies. Disassembly of the original apparatus to facilitate relocation and subsequent modifications to meet present site requirements justify a full description of the apparatus. The original R-12 cooling subsystem was supplanted by a more efficient R-502 system. The auxiliary heaters and plastic shield were removed, however power extensions were kept available for their use in future studies. The Variac power supply to the tube heater was calibrated and emplaced into a panel enclosure. See Appendix D, Apparatus Calibration for more details. A more modern Hewlet-Packard Computer/Data Acquisition system was installed and the data reduction program DRP8 was updated to account for variac calibration and program language changes.

An overall schematic representation of the experimental apparatus is shown in Figure 3.1, and a photograph is shown in Figure 3.2. The apparatus essentially consists of 8 (components: 1) a Pyrex-glass tee for the pool boiling of the R-114 liquid, "the evaporator"; (2) a Pyrex-glass tee for the condensing of the R-114 vapor, "the condenser"; (3) a R-114

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liquid reservoir; (4) a refrigerant/oil subsystem composed of an oil reservoir and a graduated oil cylinder; (5) a cooling subsystem composed of a 1/2 ton R-502 refrigeration plant, 2 positive displacement pumps and a 30 gallon water/ethylene glycol sump; (6) a vacuum pump; (7) a data acquisition and instrumentation system; (8) an aluminum/Plexi-glass framework within which components (1) through (4) were housed.

The apparatus was operated as follows: liquid R-114 was boiled in the evaporator (1), passed as vapor through the aluminum L-shaped connection and condensed in the condenser (2). R-114 condensate was returned by gravity via the distribution tube to the condenser. The R-502 refrigeration plant maintained the water/ethylene glycol mixture in the sump between -12 and -18 °C. Cooling of the sump was accomplished by a countercurrent flow heat exchanger through which an 8-gpm turbine-type pump recirculated the water/ethylene glycol mixture. An identical positive displacement pump circulated the cooled mixture through the copper condensing coils in the condenser via the control valve VC.

Prior to dismantling the evaporator in order to change out boiling tubes, the liquid R-114 was boiled out of the evaporator, condensed on the coils of the condenser then recovered to the R-114 liquid reservoir rather than returned to the evaporator. Upon reassembly, the evaporator was recharged with liquid R-114 by gravity from the reservoir. The

level in the reservoir could be topped off via the condenser from an external supply cylinder through valve V10.

Exact quantities of oil could be added to the liquid R-114 in the lower glass tee from the graduated cylinder (5) by gravity. The graduated cylinder was filled with oil by gravity from the oil reservoir through valves V14 and V2. Refilling the oil reservoir was done through valve V3 located at the top of the framework. All oil left over from the recovery of the liquid R-114 was drained out of the lower glass tee and disposed of.

The boiling tube was mounted horizontally in the evaporator and held in place by Teflon bushings with O-ring inserts. The whole system was connected to the vacuum pump (6) through valve V8 in order to remove noncondensible gases. A relief valve mounted on the aluminum L connection was set to a gage pressure limit of 20 psi, which is 50% less than the manufacturer-recommended working pressure limit of the Pyrex glass tees. All connections were assembled with Swagelok fittings sealed with Teflon ferrules to ensure leak tightness. Copper tubing of 3/8 inch diameter was used for all piping, except in the oil section, where 1/4 inch copper tubing was used.

B. BOILING TEST SECTION

1. Evaporator

The evaporator is a T-shaped container made of Corning Pyrex glass. Figure 3.3 shows a schematic of the evaporator with dimensions. Pyrex glass has several advantages: it is corrosion-resistent, transparent, has a smooth interior surface (this minimized nucleate boiling at the inner surface of the container) and is stronger with temperature and pressure variations compared to ordinary glass. The manufacturer recommended operating pressure limit of the Pyrex glass tee is 30 psi gage. Each end of the evaporator was fitted with a cast-iron flange and a gasket. A detailed sketch of the cast-iron flange is shown in Figure 3.3 also. To reduce weight upon the glass tees, two aluminum flanges, 210 mm in diameter and 12.7 mm in thickness, were bolted to the cast-iron flanges. All fittings were connected through the aluminum flanges to the Pyrex-glass evaporator.

2. Test Tube

A schematic drawing of the test tube is shown in Figure 3.4. The boiling tube was held in place by two Teflon bushings, which were attached to the aluminum flanges at both ends of the T-shaped evaporator. Four studs were used in order to attach the Teflon bushing on the aluminum flange. The Teflon bushing and both ends of the test tube were sealed by

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means of two viton O-rings that were placed between the aluminum flange and the Teflon plug at each end.

3. Boiling Tubes

A smooth, hard-copper tube, 15.9 mm (5/8 in.) in outer diameter, 12.7 mm (1/2 in) in inside diameter and 431.3 mm (17 in.) in length, was used to provide comparison data for the nucleate pool boiling heat-transfer performance of the enhanced tubes tested. All of the tubes were heated and instrumented identically. Dimensions of each tube are provided in Table V of Appendix E, Sample Calculations. Wanniarachchi *et al.* [Refs. 8, 9] and Murphy [Ref. 14] provide complete details of the tube surfaces.

The ten tubes tested were:

1. Smooth
2. GEWA-K 26 fpi (Figure 3.5)
3. GEWA-K 40 fpi (Figure 3.5)
4. GEWA-T 19 fpi (Figure 3.5)
5. GEWA-T 26 fpi (Figure 3.5)
6. GEWA-YX 26 fpi (Figure 3.6)
7. High Flux (Figure 3.7)
8. Thermoexcel-HE (Figure 3.8)
9. Thermoexcel-E (Figure 3.9)
10. Turbo-B (Figure 3.9)

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The heater was a 1000-Watt, 240-Volt stainless-steel cartridge, 6.35 mm (1/4 in.) in outer diameter and 203.2 mm (8 in) in length. It was inserted into a copper sleeve, which was 1/4 inch in inside diameter, 1/2 inch in outer diameter and 8 inches in length. In order to provide a uniform heat flux, the cartridge heater and the copper sleeve were soldered together. To minimize the thermal contact resistence, the copper sleeve was then tinned (the cartridge heater was used to maintain the solder in molten state) and inserted as a unit into the middle portion of the test tube. The active boiling length of the test tube was therefore eight inches in the middle portion of the boiling tube. In order to compute the actual average heat flux in the heated portion of the tube, a suitable correction was applied for the heat lost by natural convection out both ends. See Appendix E, Sample Calculation for details.

To measure the wall surface temperature of the boiling tube, 8 thermocouples (Type-T Teflon coated copper-constantan; 0.01 inch in diameter) were inserted into eight grooves machined on the outside of the copper sleeve. As shown in Figure 3.10, these thermocouples were located at different axial and circumferential locations. The exact locations of the thermocouples and dimensions of the thermocouple grooves are given in Figure 3.10. All the thermocouple grooves were axially machined from the location of the thermocouple hot junctions to the nearest end of the copper sleeve.

C. CONDENSER SECTION

The condenser was also a T-shaped container made of Corning Pyrex glass. It was identical to the evaporator. The position of the condenser can be seen in Figure 3.1. R-114 was condensed on a helical copper coil, which was inserted in the Pyrex-glass condenser. Copper tubing (3/8 inch outer diameter) was fabricated into a three inch diameter coil. The active condensation length was estimated to be 15 ft.

The top portion of the condenser was connected to a portable, mechanical vacuum pump to remove noncondensible gases from the apparatus. The bottom of the condenser was connected to the evaporator via valve V5 in order to return the condensed R-114 liquid to either the evaporator or the reservoir. The coolant, i.e., water/ethylene glycol mixture, entered from the top portion of the condenser. The condenser was placed vertically and connected to the vapor outlet of the evaporator using a fabricated, L-shaped aluminum tube, two inches in diameter. A Bourdon gage with a range up to a gage pressure of 150 psi and a relief valve which was set to 20 psi gage were mounted on the L-tube.

D. OIL ADDING SECTION

To study the boiling performance of R-114/oil mixtures, a cylindrical aluminum oil reservoir, 6 inches in diameter and 6 inches in height, and a graduated glass oil cylinder were installed above the evaporator as shown in Figure 3.1. The

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graduated cylinder was 355 mm in length and had a diameter of 25.4 mm. A resolution of 0.5 ml was achieved with the graduated cylinder. The oil reservoir was connected to the oil cylinder through valves V14 and V2. Refilling the oil reservoir was accomplished through valve V3 located on top of the reservoir. The addition of oil into the evaporator was achieved through V1 by gravity. The oil cylinder was refilled by gravity from the oil reservoir located above.

E.   COOLING SECTION

1. Water-Ethylene Glycol Mixture Tank

In order to store the water-ethylene glycol mixture, a special tank was manufactured. The total volume of the tank was 9243 in^3 (18.84 in x 18.84 in x 26.04 in) and it was made of 0.5 inch thick Plexiglas sheet. All sides of the tank were glued together with methylene chloride solution. The joints were held together with small screws for extra strength. The low thermal conductivity of Plexiglas was especially suited to minimize heat transfer (from room to water-ethylene glycol mixture) through the tank walls. The tank was placed on top of square wood platform on the floor and all sides were insulated with 7/8 in thick rubber sheets. The cooling mixture contained 13 gallons of ethylene-glycol and 25 gallons of distilled water. The freezing point of this mixture was about -25 deg C.

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2. R-502 Refrigeration Plant

A 1/2 ton R-502 refrigeration plant was installed to cool the water/ethylene glycol mixture. Figure 3.12 shows a schematic of the R-502 refrigeration plant. It consists of a compact-type, air-cooled condenser, a compressor, a receiver, a filter-drier unit, a pressure regulator, a temperature control switch and a thermostatic expansion valve. The evaporator of the R-502 refrigeration plant was constructed using a 3.8 inch copper tube which was run through a countercurrent heat exchanger opposite the water-ethylene glycol mixture. The temperature of the water/ethylene glycol mixture was controlled by both a thermostatic expansion valve and a temperature control switch. The R-502 refrigeration plant was adjusted to keep the temperature of the cooling liquid at about -17 deg C.

3. Pump and Control Valve

An 8 gpm, 115 VAS Burks turbine-type, positive-displacement pump was installed on the floor and the 1 inch diameter suction side of the pump was directly connected to the water/ethylene glycol tank. Cooling liquid was pumped from the tank to the condenser through the control valve VC. Also, a by-pass valve V9 was placed before the control valve VC on the discharge line. The use of the by-pass line served two important purposes: (1) it avoided overloading the pump in the event valve VC is completely closed, and (2) it provided

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proper mixing for the "warm" stream returning from the condenser. The by-pass valve required adjustment only at the highest heat fluxes to 'satisfy' proper cooling of the condenser.

F. R-114 RESERVOIR

An aluminum cylindrical reservoir, 9 inches in diameter and 10 inches in height, was placed vertically between the evaporator and condenser in order to store R-114 as a liquid. The liquid level of the R-114 could be observed by means of a sight glass attached on the reservoir. The R-114 reservoir was connected to the vapor line through valve V7 and to the liquid line through valve V6. See Figure 3.1 for the arrangement of the reservoir.

G. CHAMBER

An aluminum frame (42.13 in x 20.07 in x 24.02 in) was constructed to locate all the parts of the apparatus, except the cooling section. All four vertical sides of the frame were covered with 1/2 inch thick Plexiglas sheets and both left and right sides were provided with hinges to enable easy access to the components of the apparatus. Aluminum and plywood plates were used to cover the bottom and top sides of the frame, respectively. The valve bodies of V1 through V8 were placed inside of the front Plexiglass box. The whole frame was placed

above the water-ethylene glycol tank with aluminum supports so that the system was very compact.

One of the main advantages of this chamber was that the temperature surrounding the evaporator could be reduced relative to the ambient temperature. Also, in case of emergency, the thick Plexiglas chamber provides a safety barrier to personnel and data acquisition equipment.

H.   INSTRUMENTATION

1.   Power Measurement

A 240 volt AC source was used as the power supply, and it was adjusted by a variac in the range of 0-220 volts and 0-5 amperes according to the desired heat flux at the surface of the boiling tube. Power input to the boiling tube was measured with an AC current inductive sensor (output in volts) and a voltage sensor directly coupled to the variac output. The voltage sensor was run through a AC-DC true R.M.S. converter which output a proportional signal in volts. Figure 3.12 shows a schematic representation of the power-measurement setup. Both the AC current sensor and the AC-DC true R.M.S converter were connected to the data acquisition/control unit.

2.   Temperature Measurement

Various temperatures were monitored throughout the system to include:

1. Boiling tube wall (8 thermocouples at various longitudinal and circumferential positions)

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2. Liquid temperature (one thermocouple)

3. Vapor temperature (two thermocouples), and

4. Water/ethylene glycol mixture temperature (one thermocouple)

The locations of the wall thermocouples in the sleeve of the boiling tube are shown in Figure 3.5. The liquid and vapor thermocouples were inserted into the three specially manufactured thermocouple housings. Figure 3.14 shows a schematic of these thermocouple housings. The stainless-steel portion minimizes (owing to low thermal conductivity) errors resulting from the axial conduction of heat from the surroundings. The copper tip of the housing helps to minimize the temperature drop from the area being measured to the thermocouple location (owing to the high thermal conductivity of copper).

All the temperature measurements were accomplished by 30 gage copper-constantan thermocouples. Each thermocouple measurement was read directly by a Hewlett-Packard 3497A data acquisition system, which was controlled by a Hewlett-Packard 9826 computer. Each thermocouple was scanned twenty times over 5 seconds and the readings averaged to obtain a more accurate measurement.
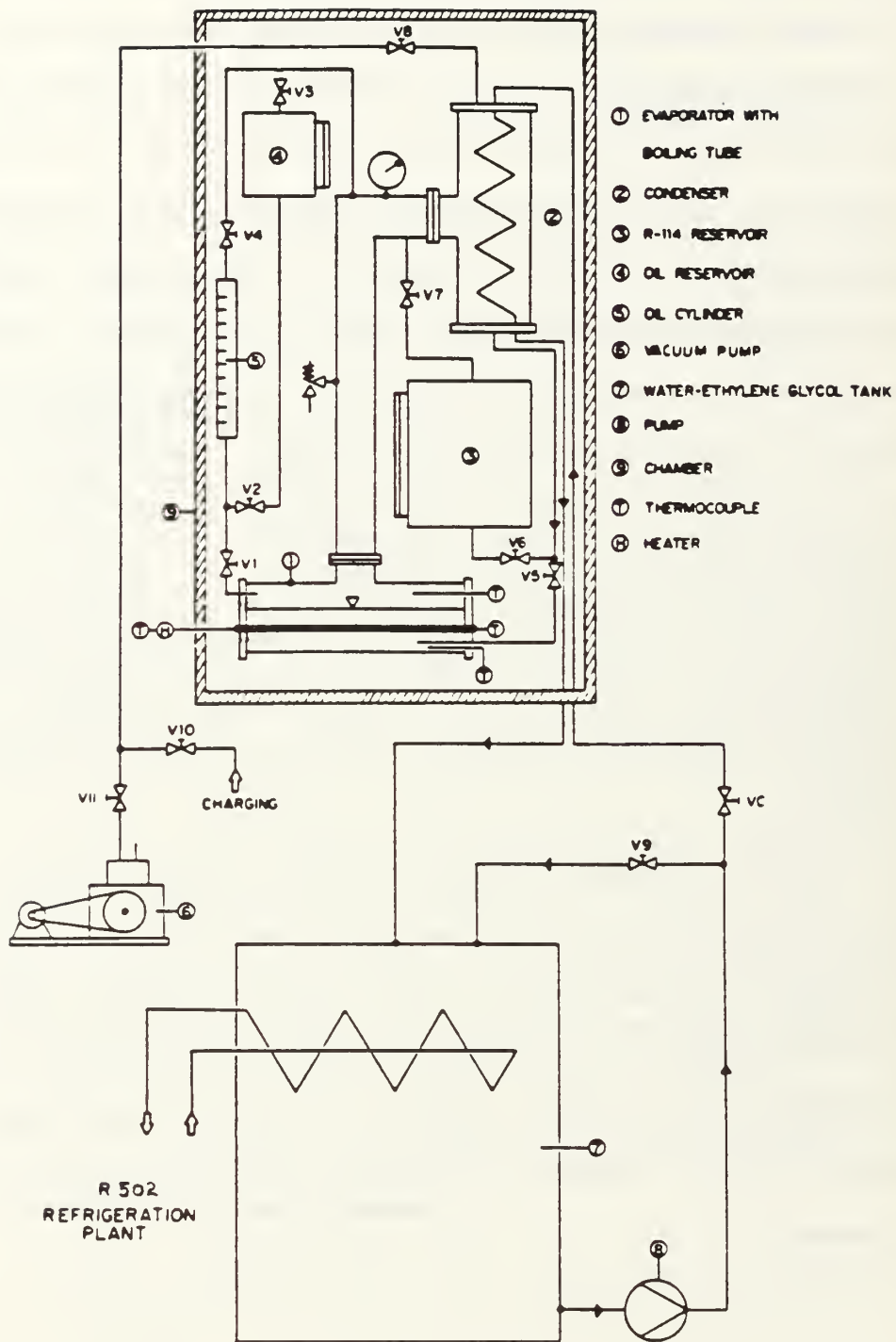
Figure 3.1   Schematic of Single Tube Apparatus
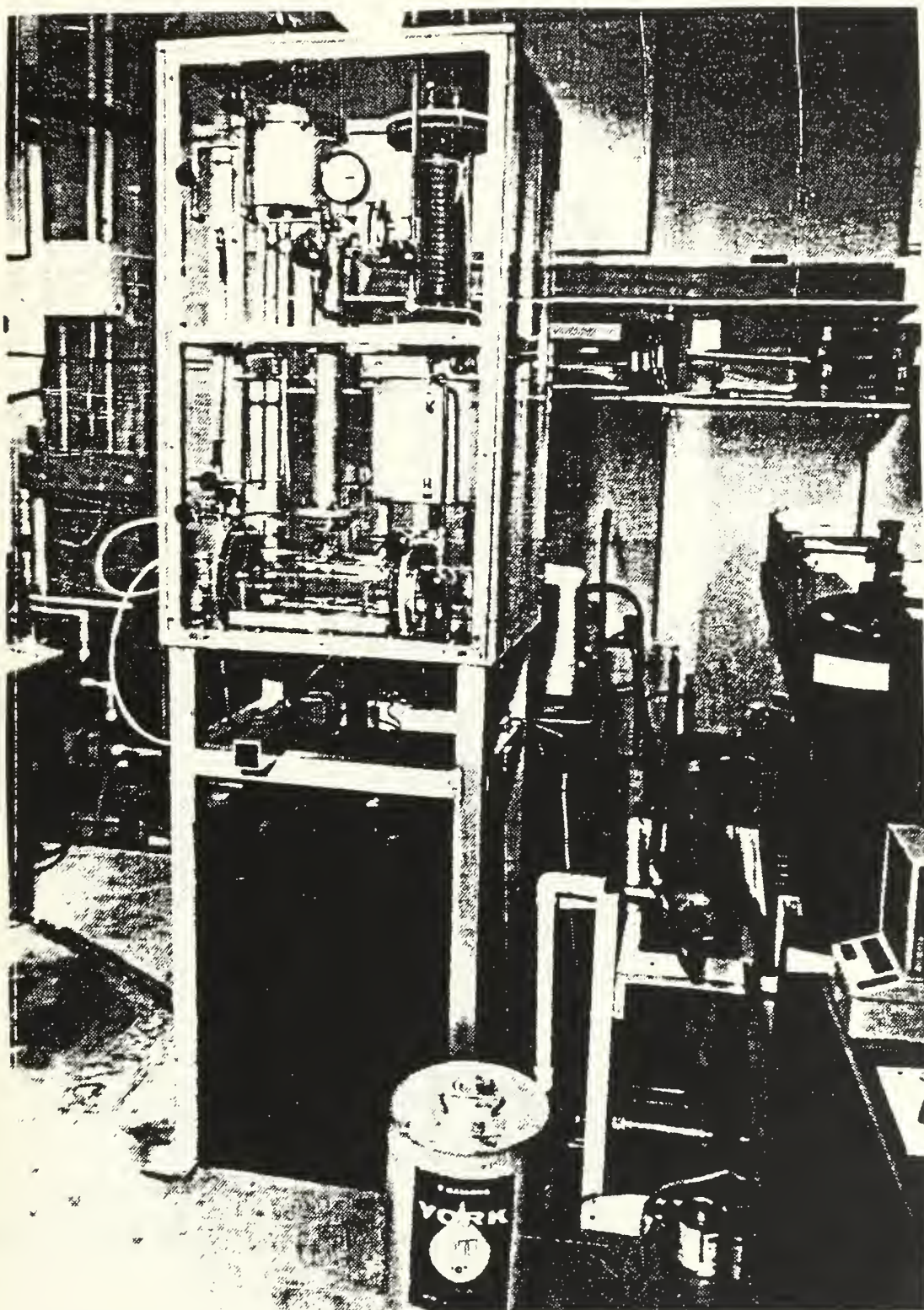
Figure 3.2   Photograph of Experimental Apparatus

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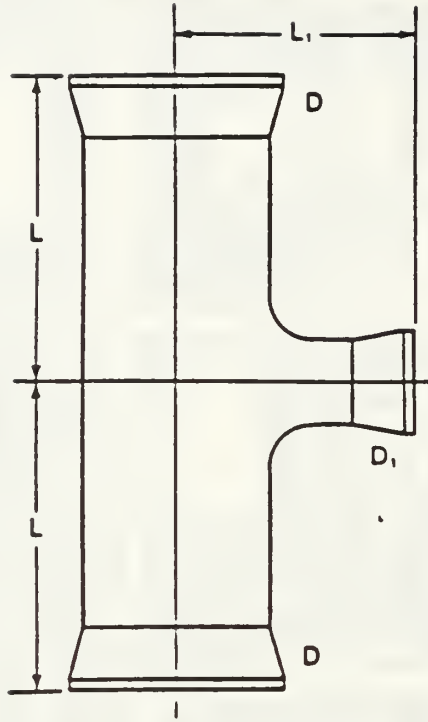
a) Corning Pyrex Glass Evaporator (D x D_1 = 402x51 mm, L = 178 mm, L_1 = 127 mm)
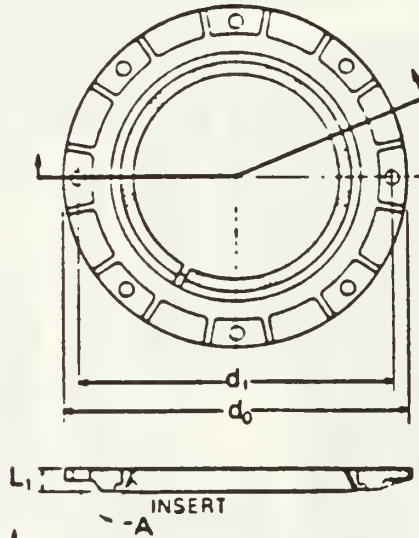
b) Cast Iron Flange and Gasket (d_1 = 190mm, d_0 = 210mm, L_1 = 14mm, A = 21°)

Figure 3.3   Schematic of the Pyrex Glass Evaporator

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ALUMINUM FLANGE

THERMOCOUPLE CHANNEL

EPOXY PLUG

HEATER

TEFLON PLUG

BOILING TUBE

COPPER SLEEVE

O-RING
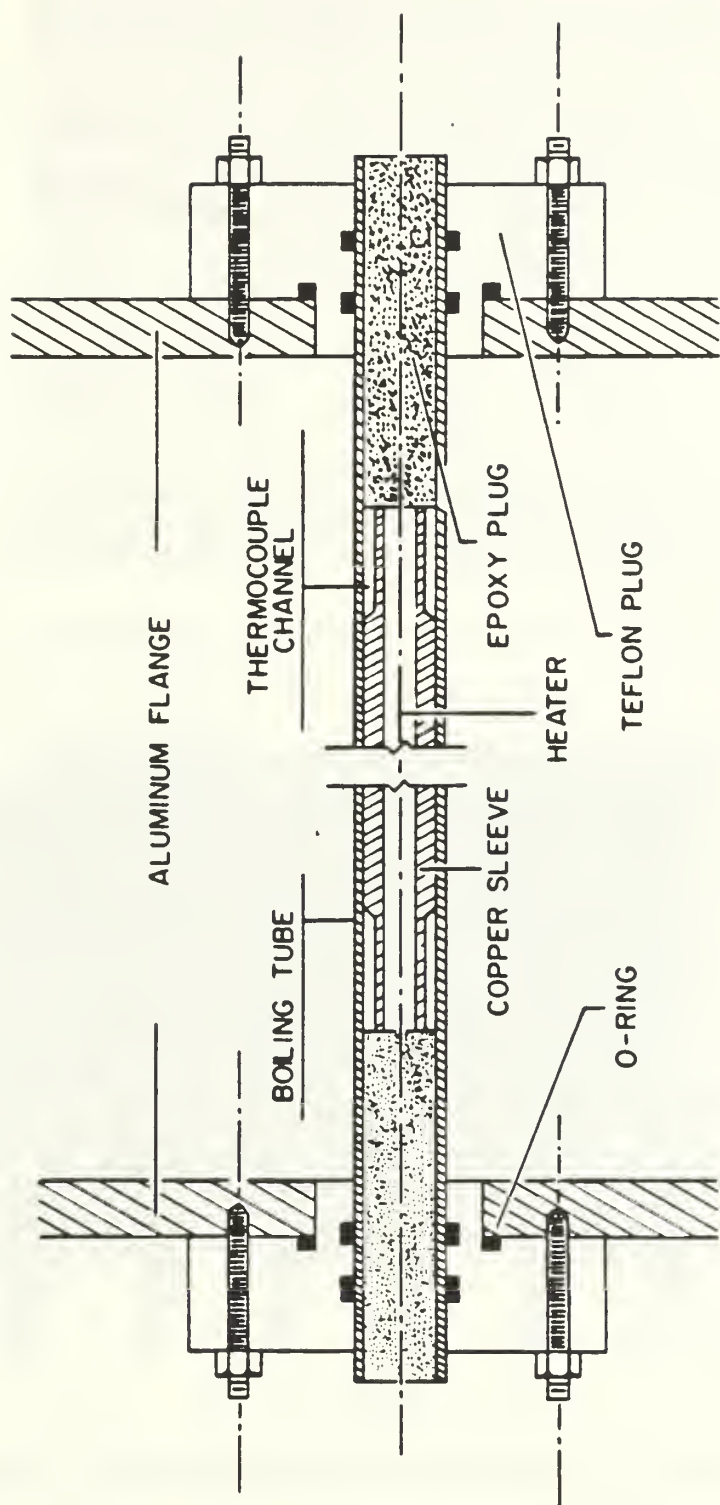
Figure 3.4   Schematic of the Boiling Test Tube

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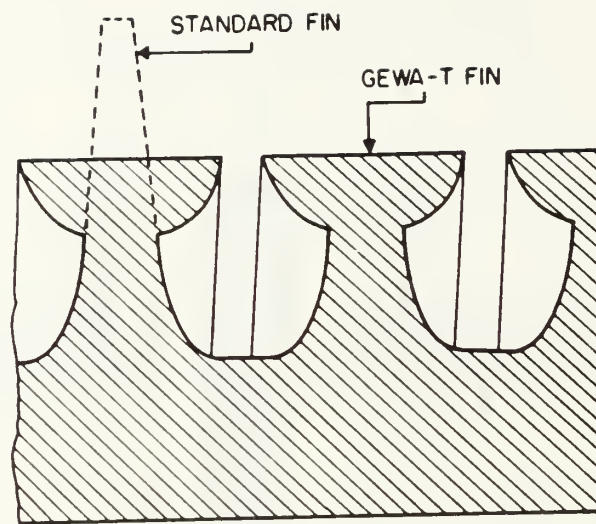
(a) Standard fin (GEWA-K) and GEWA-T fin

(b) GEWA-T fin

Figure 3.5   Schematic and Photograph of Fins

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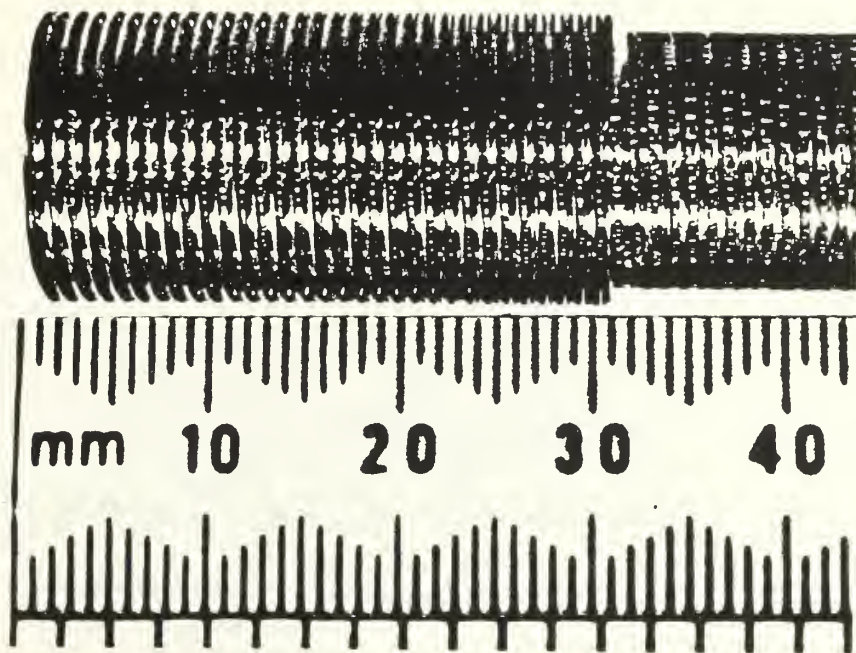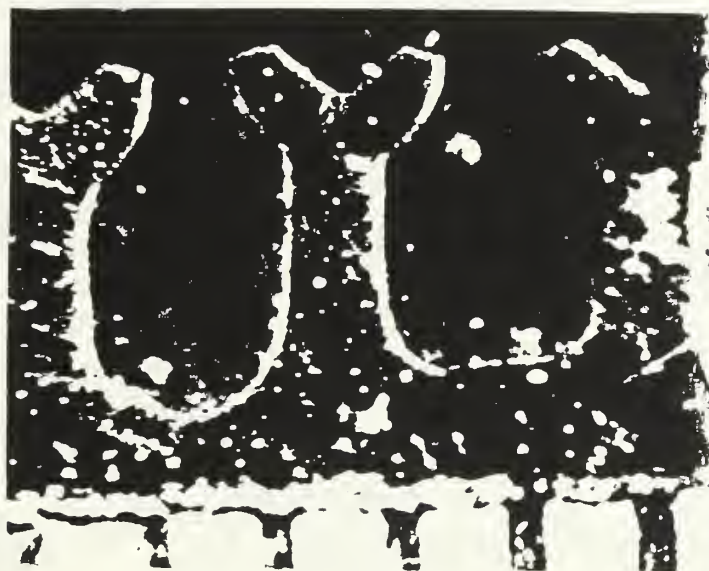
(a) GEWA-YX tube

(b) GEWA-YX fin

Figure 3.6   Photographs of GEWA-YX Tube and Fin

LIQUID IN

VAPOR OUT

VAPOR BUBBLE TRAPPED
IN ACTIVE SITE
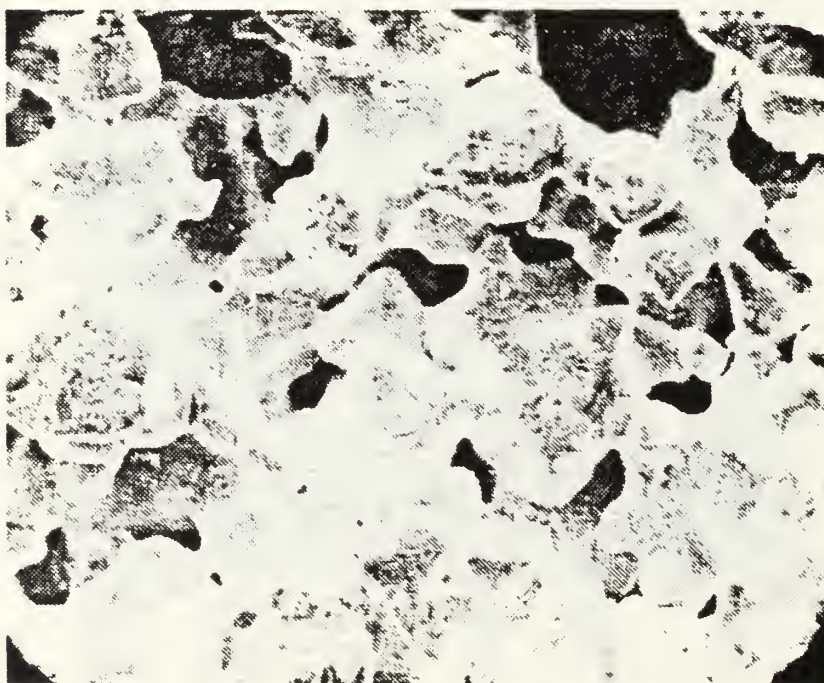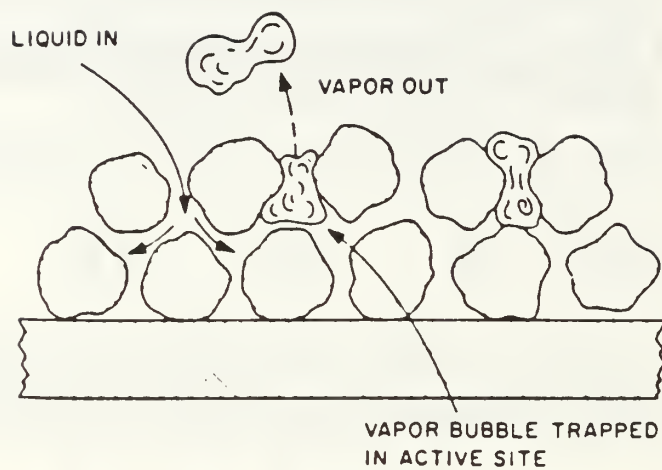
Figure 3.7   Schematic and Photograph of High Flux Surface
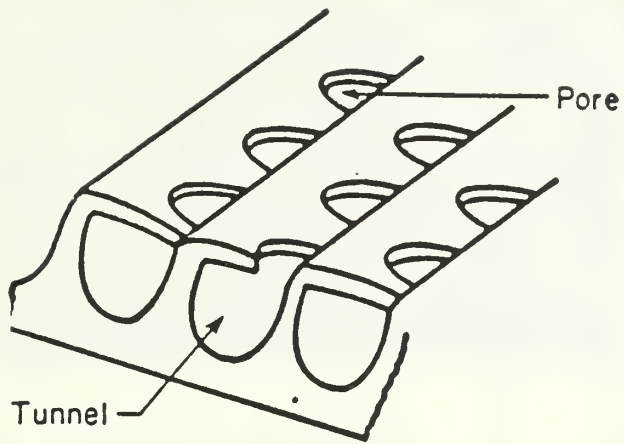
Figure 3.8 Schematic and Photograph of
Thermoexcel-HE Surface

(a) Thermoexcel-E
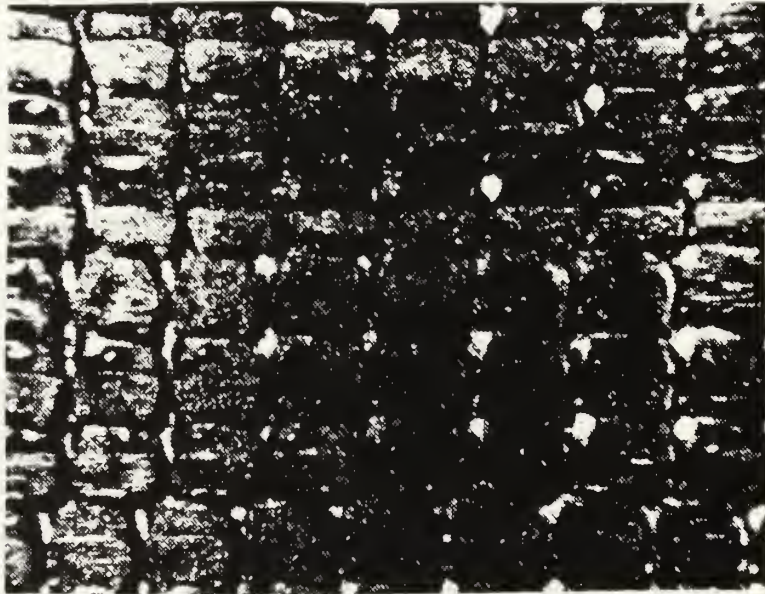
(b) Turbo-B

Figure 3.9 Photographs of Re-Entrant Cavity Surfaces

28
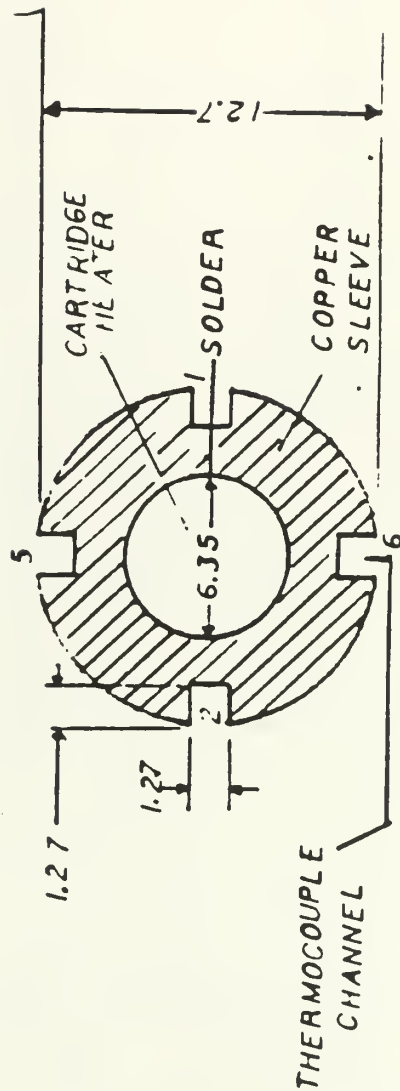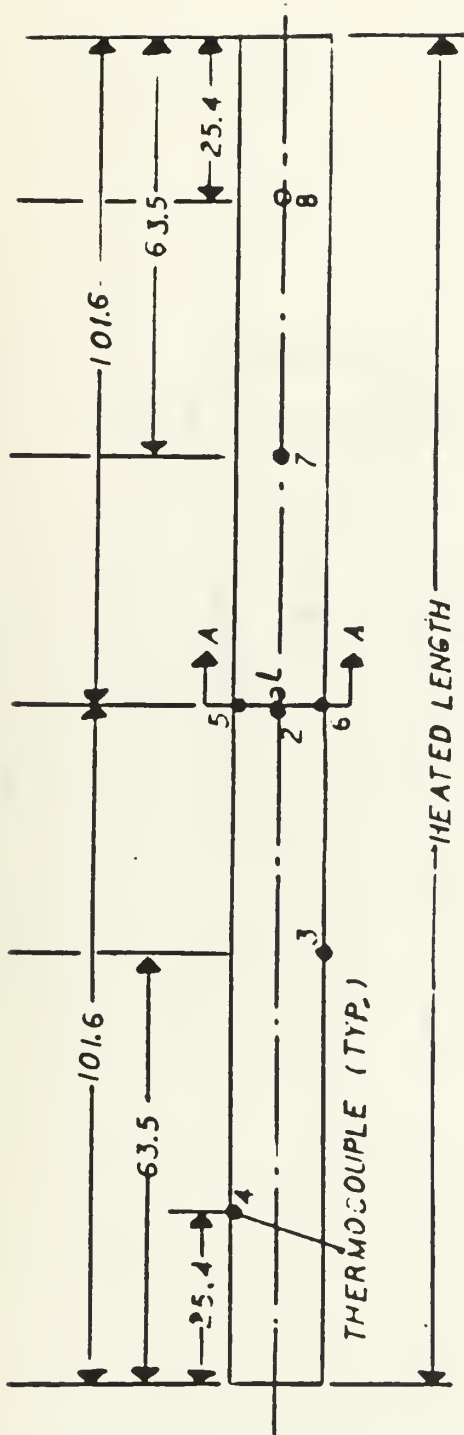
SECTION A-A (DIMENSIONS IN MM)

Figure 3.10 Positions of the Thermocouples

29
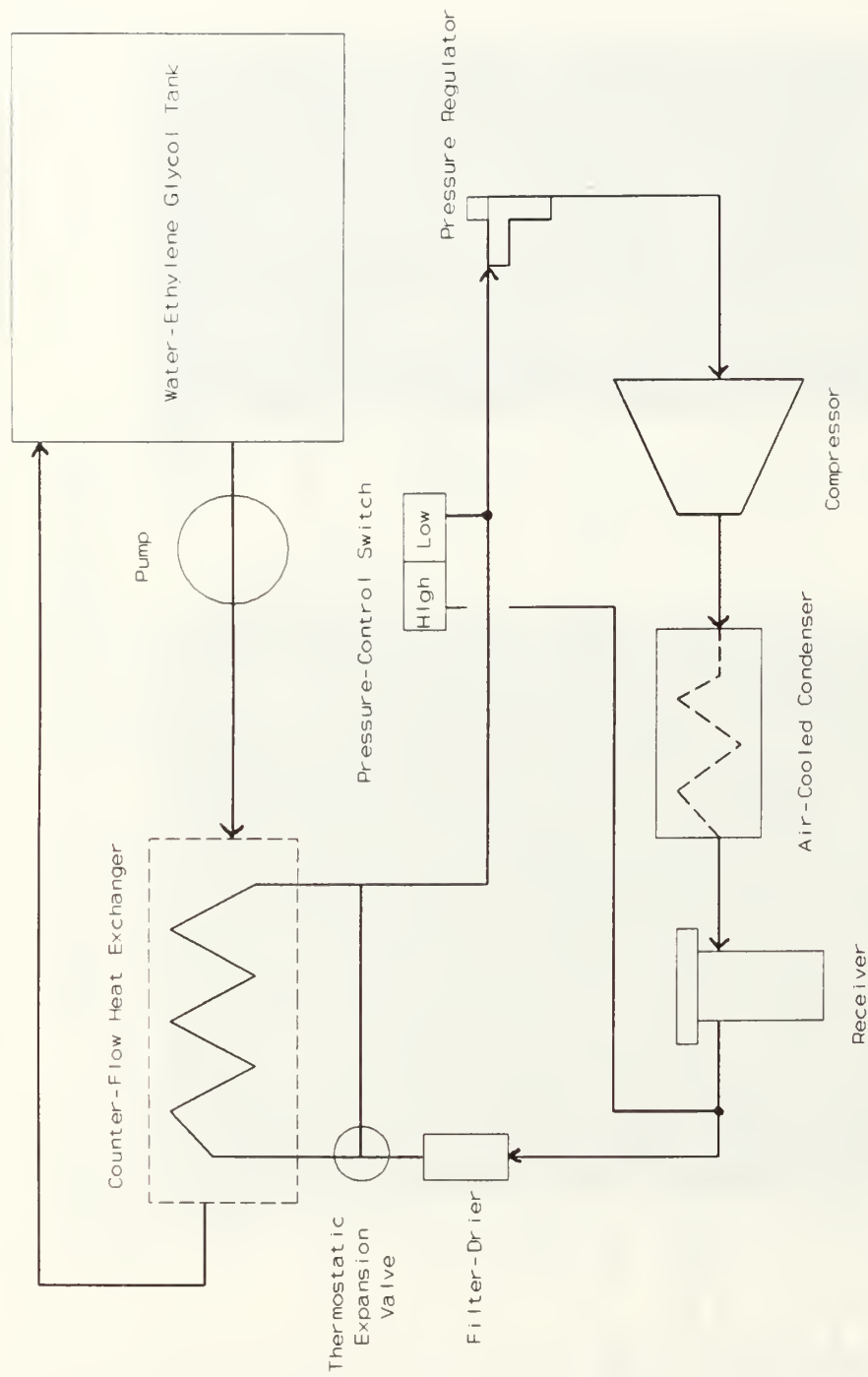
Figure 3 11 Schematic of R-502 Refrigeration System
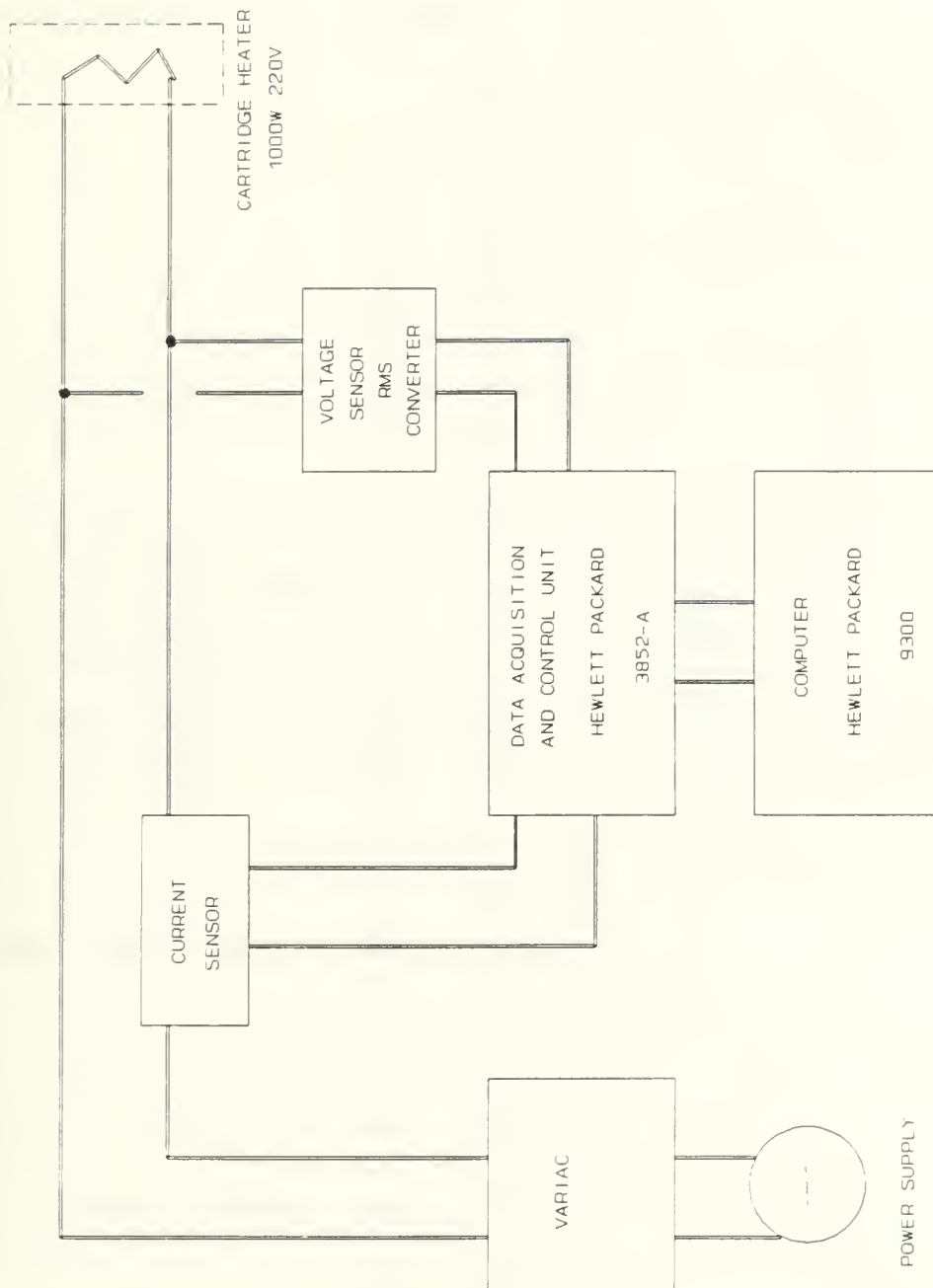
Figure 3.12. Schematic of the Power Measurement

31
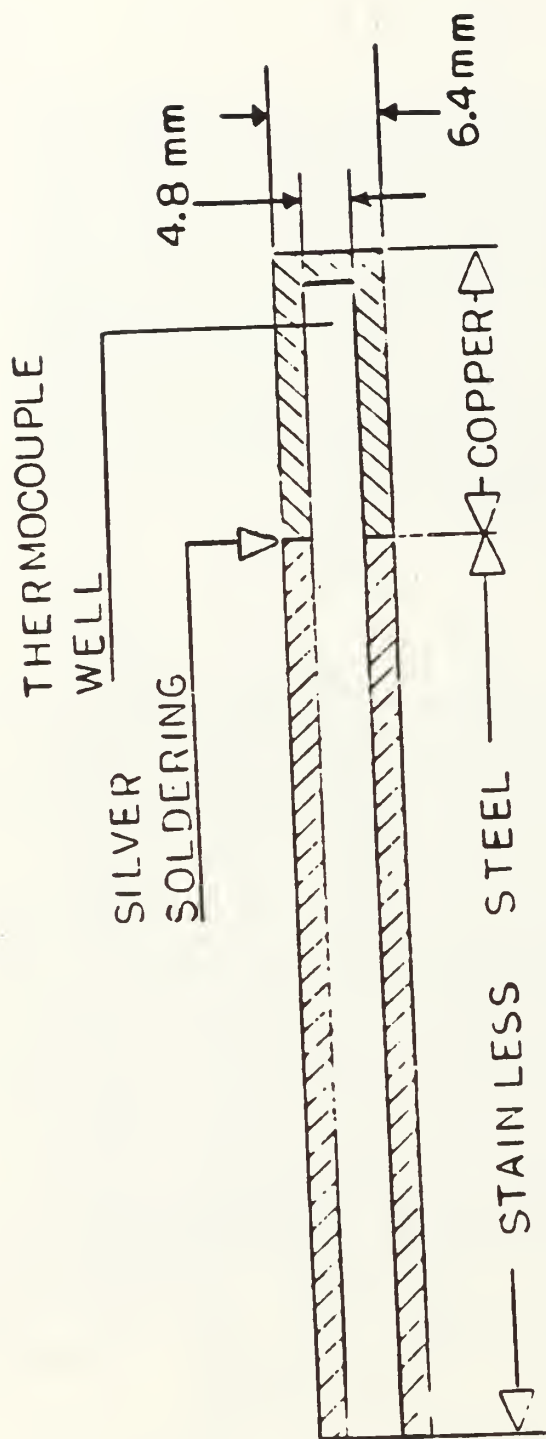
Figure 3.13 Sketch of a Thermocouple Well

IV. DATA ACQUISITION AND REDUCTION

A. DATA ACQUISITION AND STORAGE

A Hewlett-Packard 3852A automatic data acquisition unit was used to read temperatures from the thermocouples and to read current and voltage values of the cartridge heater from the AC current sensor and the AC-DC true RMS converter. A Hewlett-Packard 9000 Series computer was used to control the measurements done by the 3852A, analyze the collected data and store it.

The iterative data collection/reduction program DRP8 was loaded and run. Information was entered through the keyboard to prompt the data acquisition unit when to take data. Channel assignments are listed in Table I. The raw data was processed and transferred to a file on the computer's hard drive. A printout of the data reduction was also provided.

B. DATA REDUCTION

Following data acquisition for each data point, results were computed according to the stepwise procedure outlined in the next section, and then printed out using a Hewlett-Packard Inkjet printer. Graphs were plotted using commercial software.

C. STEPWISE DATA-COLLECTION AND SOLUTION PROCEDURE

1. Input name of user-specified file to be stored on computer hard drive.

2. Select tube type (all dimensions of the boiling test tube are included).

3. Input desired heat flux (W/m^2) and saturation temperature (°C) of the boiling liquid.

4. Set desired heat flux by adjusting VARIAC rheostat.

5. Set saturation temperature by adjusting flow of coolant through condenser coils with control valve VC.

6. Once saturation temperature is achieved, wait for steady-state conditions (at least 5 minutes) prior to taking data readings.

7. Prompt data acquisition unit to scan all channels listed in Table I (thermocouples, AC current sensor and AC-DC true RMS voltage converter). All channel readings are made in volts and stored in user specified file.

8. Convert these voltage readings to corresponding units (temperature in °C, current in amperes, voltage in volts). Karasabun [Ref. 15] describes in detail conversion equation for temperature. See Appendix B-Data Acquisition Apparatus Calibration for details of current and voltage conversion.

9. Compute the heat-transfer rate from the cartridge heater. See Appendix D-Sample Calculations.

10. Compute the average wall temperature of the boiling tube and calculate the wall superheat of the current data set. See Appendix D-Sample Calculations.

11. Compute the physical properties of R-114 using given correlations at film temperature. See Appendix D-Sample Calculations.

12. Compute the natural-convection heat-transfer coefficient of R-114 from the smooth non-boiling ends of the test tube. See Appendix D-Sample Calculations.

13. Compute heat losses from the non-boiling ends of the boiling tube. See Appendix D-Sample Calculations.

14. Calculate the heat flux from tube to the refrigerant. See Appendix D-Sample Calculations.

15. Calculate the heat transfer coefficient of the R-114 from the boiling tube. See Appendix D-Sample Calculations.

16. Store the heat flux versus wall superheat values for each data set in user-specified file.

17. Use commercial software, Harvard Graphics, to plot data.

TABLE I.   HP 3497A CHANNEL ASSIGNMENTS

Channel	Assignment
500-507	Boiling tube wall temperature
508-509	Boiling liquid temperature
510	Vapor temperature
511	Sump temperature
512	RMS voltage Tube heaters
513	Tube heater current sensor
514	Auxiliary heater current sensor

V. EXPERIMENTAL PROCEDURE

A. PREPARATION

1. Vacuum test of the Apparatus

Upon changing the tube and reassembling the apparatus, the system was evacuated down to approximately 25 in. Hg. by a portable mechanical vacuum pump through valves V11 and V8. The apparatus was allowed to stand for 30 minutes under vacuum to observe any possible leaks. During this period, thermocouples were connected to the data acquisition system, the electrical integrity of the tube heater was checked and the tube heater connected to the variac panel. If a leak was detected (i.e. an observed rise in pressure), a pressure test was conducted to isolate the source. (See V.A.2.)

2. Pressure Test of the Apparatus

In order to detect sources of leaks, the apparatus was pressurized with air up to 15 psi gage and a soap/water bubble test was carried out upon suspect joints. All detected leaks were successfully and systematically fixed.

3. Charging the Apparatus with R-114

Upon completing the pressure tests (if any), the evaporator of the apparatus was filled with R-114 liquid up to a marked position (20 mm above the top of the boiling tube) using the following procedure.

1. Valve V7 was opened to allow the pressures within the reservoir and the evacuated apparatus to equalize. It was noted that the liquid R-114 within the reservoir boiled since the equilibrium pressure was less than the R-114 vapor pressure at room temperature.

2. Valve V6 was opened to allow the liquid R-114 to drain into the evaporator by gravity.

3. At the designated evaporator level, valves V6 and V7 were closed to isolate the reservoir.

4. Degassing and Data Acquisition Channel Check.

1. With the condenser operating, the boiling tube was run at a high flux of about 100 kW/m^2 for ten minutes in order to de-gas both the tube surface and refrigerant. Care was taken not to exceed a pressure of 15 psi gage (well below manufacturer recommendation) within the apparatus.

2. Any noncondensible gases present collected in the top of the condenser. These were then removed using the vacuum pump through valves, V8 and V11.

3. The program, SETUP8, was run to check output on all thermocouple channels as well as power output. If an erroneous reading was detected, then appropriate action was taken. In the case of a faulty boiling tube wall thermocouple, the faulty thermocouple was tagged for future exclusion in data acquisition procedure. (Each thermocouple had X thermocouples embedded in its tube wall and the loss of one made no difference to the average wall temperature).

4. The apparatus was shut down and the boiling tube allowed to soak in the refrigerant overnight. This allowed for the surface to become wetted.

B. NORMAL OPERATION

The following procedure was followed to obtain the heat-transfer coefficient of pure R-114 and R-114/oil mixtures from the boiling tube being tested:

1. The R-502 refrigeration unit was operated 1-2 hours in advance in order to reduce the temperature of the water-ethylene glycol sump to a minimum of -8 °C.

2. The data acquisition/control unit, computer and variac panel were switched on.

3. The computer program Setup8 was loaded and run:
    a. All the data acquisition channels were rechecked.
    b. A power output of approximately 5W was input to the boiling tube. This has been measured to produce a heat flux of 500 to 600 W/m^2 in all tubes tested which facilitated reaching the first data point on the increasing flux run.
    c. The temperature of the refrigerant was slowly reduced down to 2.2 °C by circulating a small amount of coolant through the condenser, regulated by control valve, VC. This reduction was monitored to coincide with the reduction in sump temperature.

4. The iterative computer program DRP8 was loaded and run.

5. Two data runs were made: an increasing heat flux run and a decreasing heat flux run wherein the heat flux was incrementally increased or decreased. Ten different heat fluxes (0.6, 1, 2, 3.5, 6, 10, 20, 35, 60, and 100 kW/m^2) were selected for each increasing or decreasing heat flux data run.

6. The desired heat flux and saturation temperature were input to the program as reference points for each data point.

7. The variac was adjusted to set the actual heat flux which was continuously compared to the desired heat flux by the program until they agreed within 2 percent.

8. The control valve VC was adjusted to regulate the flow of cooling liquid through the condenser to maintain nearly constant saturation temperature at a given heat flux. Desired versus actual saturation temperatures were monitored continuously by the program until they agreed ± 0.1 °C.

9. For each data point, conditions in the evaporator were allowed to stabilize for at least 5 minutes prior to measuring the raw data. The following raw data were measured and stored in a user specified file: boiling tube wall thermocouple readings, liquid bulk

thermocouple readings, vapor thermocouple readings, sump thermocouple readings, current sensor readings, and voltage sensor readings.

10. Two data points were taken at a given heat flux and saturation temperature to comprise a data set. The following processed data were recorded as a printout: wall temperatures of the boiling section, liquid bulk temperatures, vapor temperature, sump temperature, wall superheat, heat transfer coefficient of the R-114/R-114-oil mixture and the actual heat flux.

11. For each data set, the above procedure beginning with step 5 was repeated.

12. Table II provides a listing of all data runs.

TABLE II. LISTING OF DATA RUNS

Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
1	DATA630I5	HF	I	0	CAL
2	DATA630D5	HF	D	0	CAL
3	DATA702I5	HF	I	0	CAL
4	DATA702D5	HF	D	0	CAL
5	DATA0705I5	HF	I	0	CAL\DATA
8	DATA0705D5	HF	D	0	CAL\DATA
7	DATA0709D4	SM	I	0	DATA
8	DATA0709D4	SM	D	0	DATA
9	DAT0710I6	GK-40	I	0	DATA
10	DAT0710D6	GK-40	D	0	DATA
11	DAT0711I7	GK-26	I	0	DATA
12	DAT0711D7	GK-26	D	0	DATA
13	DAT0715I8	GT-19	I	0	DATA
14	DAT0715D8	GT-19	D	0	DATA
15	DAT0716I9	GT-26	I	0	DATA

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Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
16	DAT0716D9	GT-26	D	5	DATA
17	DAT0717I11	T-HE	I	5	DATA\DG
18	DAT0717D11	T-HE	D	0	DATA
19	DAT0722I12	TB	I	0	DATA
20	DAT0722D12	TB	D	0	DATA
20	DAT0723I09	GY-26	I	0	DATA
22	DAT0723D09	GY-26	D	0	DATA
23	DAT0724I11	T-HE	I	0	DATA\DG
24	DAT0724D11	T-HE	D	0	DATA\REP
25	DAT0803I4	SM	I	0	DATA\REP
26	DAT0803D4	SM	D	5	DATA\REP
27	DAT0804D4	SM	I	0	DATA
28	DAT0804D4	SM	D	0	DATA
29	DAT0805D4	SM	I	10	DATA
30	DAT0805D4	SM	D	10	DATA
31	DAT0806I7	GK-26	I	0	DATA\REP
32	DAT0806D7	GK-26	D	0	DATA\REP
38	DAT0807I7	GK-26	I	3	DATA
34	DAT0808I7	GK-26	D	0	DATA
35	DAT0808I7	GK-26	I	10	DATA
36	DAT0808D7	GK-26	D	10	DATA
37	DAT0809I6	GK-40	I	5	DATA\REP
38	DAT0810D6	GK-40	D	0	DATA\REP
36	DAT0810I6	GK-40	I	3	DATA
40	DAT0810D6	GK-40	D	3	DATA
41	DAT0812I6	GK-40	I	10	DATA
42	DAT0812D6	GK-40	D	10	DATA
43	DAT0815I8	GT-19	I	0	DATA\REP

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Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
44	DAT0815D8	GT-19	D	3	DATA\REP
45	DAT0816I8	GT-29	I	3	DATA
46	DAT0816I8	GT-19	D	3	DATA
48	DAT0820D8	GT-19	I	10	DATA
48	DAT0820D8	GT-19	D	10	DATA
49	DAT0821I9	GT-26	I	3	DATA
50	DAT0821D9	GT-26	D	3	DATA
51	DAT0822I9	GT-26	I	10	DATA
52	DAT0822D9	GT-26	D	10	DATA
53	DAT0823I10	T-E	I	3	DATA
50	DAT0823D10	T-E	D	3	DATA
55	DAT0824D10	T-E	I	10	DATA
56	DAT0824D10	T-E	D	10	DATA
57	DAT0825D9	GY-26	I	3	DATA
56	DAT0825D9	GY-26	D	3	DATA
56	DAT0826I9	GY-26	I	10	DATA
60	DAT0828D5	GY-26	D	10	DATA
61	DAT0828I5	HF	I	3	DATA
62	DAT0827D5	HF	D	3	DATA
63	DAT0828I5	HF	I	10	DATA
64	DAT0828D5	HF	D	10	DATA
68	DAT0829D12	TB	I	3	DATA
66	DAT0829D12	TB	D	3	DATA
68	DAT0830I12	TB	I	10	DATA
68	DAT0830D12	TB	D	10	DATA
69	DAT0831I11	T-HE	I	3	DATA
70	DAT0831D11	T-HE	D	3	DATA
71	DAT0901I11	T-HE	I	10	DATA

Data Run #	Data File	Tube	Heat Flux	Oil (%)	Purpose
72	DAT0901D11	T-HE	D	10	DATA
73	DAT0906I10	T-E	I	0	DATA
74	DAT0906D10	T-E	D	0	DATA

```
SM = Smooth   GK-26 = GEWA-K 26 fpi         GK-40 = GEWA-K 40 fpi
HF = High Flux      GT-19 = GEWA-T 19 fpi         GT-26 = GEWA-T 26 fpi
TB = Turbo-B GY-26 = GEWA-YX 26 fpi     T-E = Thermoexcel-E
T-HE = Thermoexcel-HE
I = Increasing Flux           D = Decreasing Flux

CAL = CALIBRATION DATA                  DATA = BASELINE DATA
REP = REPEATABILITY DATA                DG = DEGASSING DATA
```

VI. RESULTS AND DISCUSSION

A. REPRODUCIBILITY

To test the reproducibility of the experimental data, 9 data runs were repeated on different days. All data runs were conducted at a saturation temperature of 2.2 °C. Figure 6.1 shows a comparison of two pairs of runs, 13, 14, and 43, 44 for increasing and decreasing heat flux. It can be seen that there is excellent agreement between both the increasing and decreasing heat flux runs.

B. COMPARISON OF DATA WITH PREDICTION

To check the general validity of the data obtained, four well-known correlations, two for natural convection and two for nucleate pool boiling, were plotted and compared with the smooth tube data for pure R-114. The two natural convection correlations used were Churchill and Chu [Ref. 1] and a more recent update Churchill and Usagi [Ref. 2]. The two nucleate pool boiling correlations used were: Rohsenow [Ref. 1] and Stephan-Abdelsalam [Ref. 3]. One of the first correlations developed, the Rohsenow correlation is based upon the physics of pool boiling heat transfer. It applies only for clean surfaces and when used to estimate heat flux, errors can amount to ± 100%. The Stephan-Abdelsalam correlation for refrigerants was developed from application of regression

analysis to a large amount of existing data. Application to a large number of pure substances of widely differing thermal properties is remarkably simple. Figure 6.2 shows the plotted data and correlations. It can be seen from the plot that there is excellent agreement for natural convection and not bad agreement in the nucleate boiling region. The slightly worse agreement for nucleate boiling can be attributed to the more complex mechanisms at work in this region.

C. EFFECTS OF DEGASSING

Early experiments (Runs 1-6) conducted with the High Flux tube pointed out the significant effect of degassing both the tube surface and refrigerant. It was observed that tubes that were not vigorously boiled after placement into the apparatus and not allowed to settle overnight, tended to nucleate at very low heat fluxes the following day when conducting an increasing heat flux run. Similar effects were observed if the apparatus was allowed to stand undisturbed for several days. The most extreme effects were seen for the re-entrant cavity tubes. Figure 6.3 shows the change in behavior (i.e. for gassed and degassed) for a Thermoexcel-E tube for an increasing heat flux run. For the degassed case, an extreme temperature overshoot was observed, which indicates a large number of nucleation sites were deactivated. Once all nucleation sites were activated, the performance of both cases was identical. It can be surmised that the entrapment of vapor

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bubbles in surface cavities as well as the outgassing from the Teflon O-rings of the rig over time, enhanced the nucleation on the tube surfaces. Vigorous boiling removed those gases from both surface and liquid.

D. BOILING PERFORMANCE OF ENHANCED TUBES IN PURE R-114 AND R-114/OIL MIXTURES

The results of the 74 data runs are discussed with references to the figures (Figures 6.1 to 6.80) that are provided at the end of this chapter. Performance of each tube will be presented and discussed as follows:

1. For pure R-114

2. For R-114/oil mixtures (3% and 10% by weight)

3. Comparison of pure R-114 and R-114/oil mixtures for increasing heat flux runs.

4. Comparison of pure R-114 and R-114/oil mixtures for decreasing heat flux runs.

5. Comparison to similar tube types (i.e. finned - as applicable for each R-114/oil mixture for both increasing and decreasing heat flux runs)

1. Boiling Performance of Smooth Tube

Figures 6.4, 6.5 and 6.6 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a smooth copper tube. Figures 6.7 and 6.8 show the comparative performance for the three refrigerant/oil mixtures on increasing and decreasing heat flux respectively. It can be seen that in Figure 6.7 in the natural convection region there is slight degradation with

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increases in oil. However, in the nucleate boiling region there is significant degradation with increasing oil concentration. Wanniarachi *et al.* [Ref. 6] reported similar behavior for smooth tubes. This behavior was attributed to two competing effects: (1) the 'choking' of the tube surface by an oil rich layer which develops as the more volatile refrigerant is boiled off; () the diffusion of the miscible oil rich layer back into the bulk fluid. In the natural convection region it can be surmised that the diffusion effect predominates while in the nucleate boiling region the 'choking' effect eventually overwhelms the diffusion. This degradation is seen again in Figure 6.8. It can be seen that in Figure 6.8 that as conditions approach natural convection along the decreasing heat flux curve, the three mixtures perform similarly as nucleation sites die out.

2. Boiling Performance of Finned/Modified Finned Tubes

Figures 6.9, 6.10 and 6.11 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a standard 26 fpi tube, (GEWA-K). At a heat flux of 35 kW/m², heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil and R-114/10% oil was 2.4, 2.9 and 3.2 respectively. Figures 6.12 and 6.13 show the comparative performance of the three refrigerant/oil mixtures on increasing heat flux and decreasing heat flux runs

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respectively. On increasing heat flux and decreasing heat flux runs, the finned tube only shows a small degradation in both the natural convection and nucleate boiling regions. The smooth tube only shows small degradation in the natural convection region. Also, at the higher heat fluxes, the R-114/3% oil mixture shows a slightly better performance than the pure R-114 and R-114/10% oil mixture. This phenomenon was observed for all finned tubes, however, the reasons for such behavior are not fully understood; it may be due to bubble 'scouring' between the fins. This small increase in performance at low oil concentrations agrees with results reported by Stephan and Mitrovic [Ref. 15].

Figures 6.14, 6.15 and 6.16 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a GEWA-K 40 fpi tube. Figures 6.17 and 6.18 show the comparative performance of the three refrigerant/oil mixtures on increasing heat flux and decreasing heat flux respectively. Similar behavior to the GEWA-K 26 fpi tube was observed including the improved performance at higher fluxes at low oil concentrations (3%).

Figures 6.19, 6.21, and 6.23 show the comparative performance of the three R-114/oil mixtures boiling from GEWA-K 26 and 40 fpi tubes on increasing heat flux. For all three oil concentrations, the GEWA-K 40 fpi tube outperforms the GEWA-K 26 fpi and smooth tubes consistently in the nucleate boiling region. At a heat flux of 35 kW/m^2 the GEWA-K 40 fpi

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and the GEWA-K 26 fpi had heat transfer enhancements of 4.1 and 3.1 respectively over the smooth tube for pure R-114. Similar enhancements were seen at R-114/3% oil and R-114/10% oil mixtures. See Table III at end of this chapter. In the natural convection region, the results were mixed. Neither tube predominated consistently for pure R-114 and R-114/oil mixtures. Figures 6.20, 6.22 and 6.24 show similar comparisons on decreasing heat flux. It can be seen that the GEWA-K 40 fpi performs best in all three cases except at very low fluxes where results were less certain. However, the calculation for the heat flux did not take into account the actual increases in surface area for the finned tubes over the smooth tube. A fin root diameter was used to calculate surface area. The actual area increase is of the same magnitude as the heat transfer enhancements seen, indicating that both smooth and finned tubes give similar heat transfer performance. To demonstrate this, Figure 6.9, the GEWA-K 26 fpi tube in pure R-114, is replotted in Figure 6.81 using the actual fin surface area. The ratio of actual fin surface area to root diameter area was a factor of 4. Actual surface heat flux was calculated by dividing the root diameter surface heat flux by four. It can be seen in Figure 6.81 that in the natural convection region the GEWA-K 26 fpi tube performs comparably to the smooth tube. However, in the mixed boiling and nucleate boiling regions the GEWA-K 26 fpi tube shows an enhanced performance over the smooth tube up to three, which indicates

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there are other mechanisms involved besides increased surface area.

Figures 6.25, 6.26 and 6.27 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a modified fin tube, GEWA-T 19 fpi. At a heat flux of 35 kW/m^2, the heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.1, 4.3 and 5.2 respectively. Figures 6.28 and 6.29 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. Similar to the GEWA-K type tube, only a slight degradation is observed in both the natural convection and nucleate boiling regions. Again at higher heat fluxes, the R-114/3% oil mixture performed best.

Figures 6.30, 6.31 and 6.32 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from a GEWA-T 26 fpi tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.7, 4.6 and 4.8 respectively. Figures 6.33 and 6.34 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing oil mixtures respectively. It can be seen that at higher heat fluxes, the R-114/3% oil mixture performed best and there was significant degradation in performance for the R-114/10% oil

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mixture compared to the smooth tube. At lower heat fluxes, the pure R-114 outperformed the refrigerant/oil mixtures. It can be surmised that the 'choking' effect predominates for the refrigerant/oil mixtures.

Figures 6.35, 6.37 and 6.39 show the comparative heat transfer performance of each refrigerant/oil mixture boiling from the GEWA-T 19 and 26 fpi tubes for increasing heat fluxes. Figures 6.36, 6.38 and 6.40 show similar comparisons for decreasing heat fluxes. It can be seen that in the nucleate boiling region at the higher heat fluxes that the GEWA-T 26 fpi tube performed best. At the lower heat fluxes, in the natural convection region for an increasing heat flux run the tubes performed equally. For a decreasing heat flux run, the GEWA-T 19 fpi performed best. Recalling the channel structure of the GEWA-T tube suggests more complex phenomena than simple increase in surface area. Indeed Marto *et al.* [Ref. 16] have found that the gap width with GEWA-T tubes has a significant effect on boiling performance. Down to some limiting value, decreasing the gap width generally increases heat transfer coefficient. The enhancement can be attributed to strong interaction between heat transfer and hydrodynamic effects within GEWA-T channels.

Figures 6.41, 6.42 and 6.43 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from another modified fin tube, GEWA-YX 26 fpi. At a heat flux of 35 kW/m^2, heat

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transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 3.4, 4.3 and 4.4 respectively. Figures 6,44 and 6.45 show comparative performance for the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. It can be seen that in the natural convection region slight degradation in performance occurs. At the higher fluxes in the nucleate boiling region, the R-114/3% oil mixture performed best as seen with other types of finned tubes.

Figures 6.46, 6.48 and 6.50 show the comparative performance for each refrigerant/oil mixture boiling from the GEWA-K, GEWA-T and GEWA-YX 26 fpi tubes for increasing heat fluxes. Figures 6.47, 6.49 and 6.51 show similar comparisons for decreasing heat fluxes. Both the modified finned tubes, GEWA-T and GEWA-YX, show marked increases in performance over the standard finned tube, GEWA-K, in the nucleate boiling region. Results were not so clear however in the natural convection region, possibly due to variation in surface area.

3. Boiling Performance of High Flux Tube

Figures 6.52, 6.53 and 6.54 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the High Flux tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 6.4, 6.2 and 3.8. The High Flux tube

displays a much larger relative temperature overshoot compared to the smooth tube and its point of incipience occurs at a much lower heat flux. Accuracy of the data was greatest at high heat flux and large superheat values (± 3.8%) and most uncertain at low heat flux and small superheat values (± 17.15%). See Uncertainty Analysis-Appendix E. It can be seen that at higher heat fluxes that the High Flux tube in the R-114/10 oil mixture performed almost equally to the smooth tube. At a heat flux of 100 kW/m^2 the heat transfer enhancement compared to the smooth tube was 1.1. Wanniarachchi *et al.* [Ref. 7] reported similar results. The marked decrease in boiling performance was attributed to the creation of an oil-rich layer within the boiling pores. The superior boiling performance for R-114/10% oil mixture compared to the smooth tube is completely recovered when the heat flux is decreased. It can be seen that in the natural convection region the performance of the High Flux tube is comparable at all oil concentrations to the smooth tube which indicates there is no effect of either tube type or oil concentration in this region. Figures 6.55 and 6.56 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. The extreme rate of degradation of performance of the High Flux surface at 10% oil concentration with increasing heat flux is clearly seen as well as its complete recovery as the heat flux is decreased.

4. Boiling Performance of the Thermoexcel Tubes

Figures 6.57, 6.58 and 6.59 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Thermoexcel-E Tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 5.7, 5.3 and 5.2 respectively. Figures 6.60 and 6.61 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat fluxes respectively. As seen with the High Flux tube, the Thermoexcel-E tube performed equally to the smooth tube in the natural convection region for all refrigerant/oil mixtures.

Figures 6.62, 6.63 and 6.64 show the heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Thermoexcel-HE tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/3% oil mixture and R-114/10% oil mixture was 4.8, 5.1 and 4.8. Similar performance to the Thermoexcel-E tube was observed. Figures 6.65 and 6.66 show the comparative performance of the three refrigerant/oil mixtures on increasing and decreasing heat flux respectively. At a higher heat flux of 100 kW/m^2 the heat transfer enhancements compared to the smooth tube for the R-114/3% oil mixture and R-114/10% oil mixture was reduced to 2.2 and 1.9.

Figures 6.67, 6.69 and 6.71 show the comparative performance of each refrigerant/oil mixture boiling from both the Thermoexcel-E and HE tubes for increasing heat fluxes. Figures 6.68, 6.70 and 6.72 show similar comparisons on decreasing heat fluxes. As discussed earlier both tubes showed improved performance over the smooth tube in the nucleate boiling region. It can be seen that the Thermoexcel-HE tube performed marginally better than the Thermoexcel-E at high heat fluxes. In the natural-convection region both tubes performed comparably to the smooth tube. Wanniarachchi et al [Ref. 8] reported similar behavior for Thermoexcel-E and Thermoexcel-HE tubes. It can be surmised that in the natural convection region the small re-entrant cavities of both tubes do not increase the total boiling surface area like fins. The Thermoexcel-E and HE tubes 'appear' smooth and would be expected to perform comparably to the smooth tube which was indeed seen.

5. **Boiling Performance of the Turbo-B Tube**

Figures 6.73, 6.74 and 6.75 show heat transfer performance of pure R-114, R-114/3% oil mixture and R-114/10% oil mixture respectively, boiling from the Turbo-B tube. At a heat flux of 35 kW/m^2, heat transfer enhancement compared to the smooth tube for pure R-114, R-114/oil mixture and R-114/10% oil mixture was 6.2, 6.7 and 5.6 respectively. As seen with all previous re-entrant tubes tested, comparable

performance with the smooth tube is observed in the natural convection region and marked improved performance over the smooth tube is observed in the nucleate boiling region. Figures 6.76 and 6.77 show the comparative performance of each refrigerant/oil mixtures boiling from the Turbo-B tube on increasing and decreasing heat fluxes respectively. Similar to the other re-entrant cavity surfaces tested, the R-114/10% oil mixture had the greatest rate of degradation for increasing heat flux in the nucleate boiling region.

6. Overall Performance of Smooth and Enhanced Surfaces

Figures 6.78, 6.79 and 6.80 show the comparative performance of 8 of the 10 tube surfaces tested. The other two, Thermoexcel-E and GEWA-T 19 fpi, performed similarly to the Thermoexcel-HE and GEWA-T 26 fpi respectively, and so are not included. Three distinct groups of tubes can be identified based upon boiling heat transfer performance at all oil concentrations. These are: (1) smooth, (2) finned/modified finned and (3) re-entrant cavity. Within the finned/modified finned group, it can be seen that the GEWA-T is the best performer. Its enhanced performance was attributed to its channel geometry. The High Flux tube in R-114/10% oil mixture performed comparably to the smooth tube (heat transfer enhancement was 1.1) at a heat flux of 100 kW/m^2. The severe degradation in performance for the High Flux tube can be attributed to the 'choking' of the porous surface. Table III

shows numerically the enhancement in performance over the smooth tube for all three refrigerant/oil mixtures boiling from each of the tubes for three heat fluxes of 10, 35 and 100 kW/m^2. It can be seen at the moderate heat flux of 35 kW/m^2, the finned/modified finned tubes show enhanced performances of 2.4 to 5.2 over the smooth tube while the re-entrant cavity tubes show enhancements of 3.8 to 6.7 over the smooth tube. The effect of oil concentration is significant at high heat fluxes. At a heat flux of 100 kW/m^2 for pure R-114, the finned and re-entrant cavity tubes show comparable enhancement compared to the smooth tube. For R-114/10% oil mixtures at a heat flux of 100 kW/m^2, the finned tubes performed best.
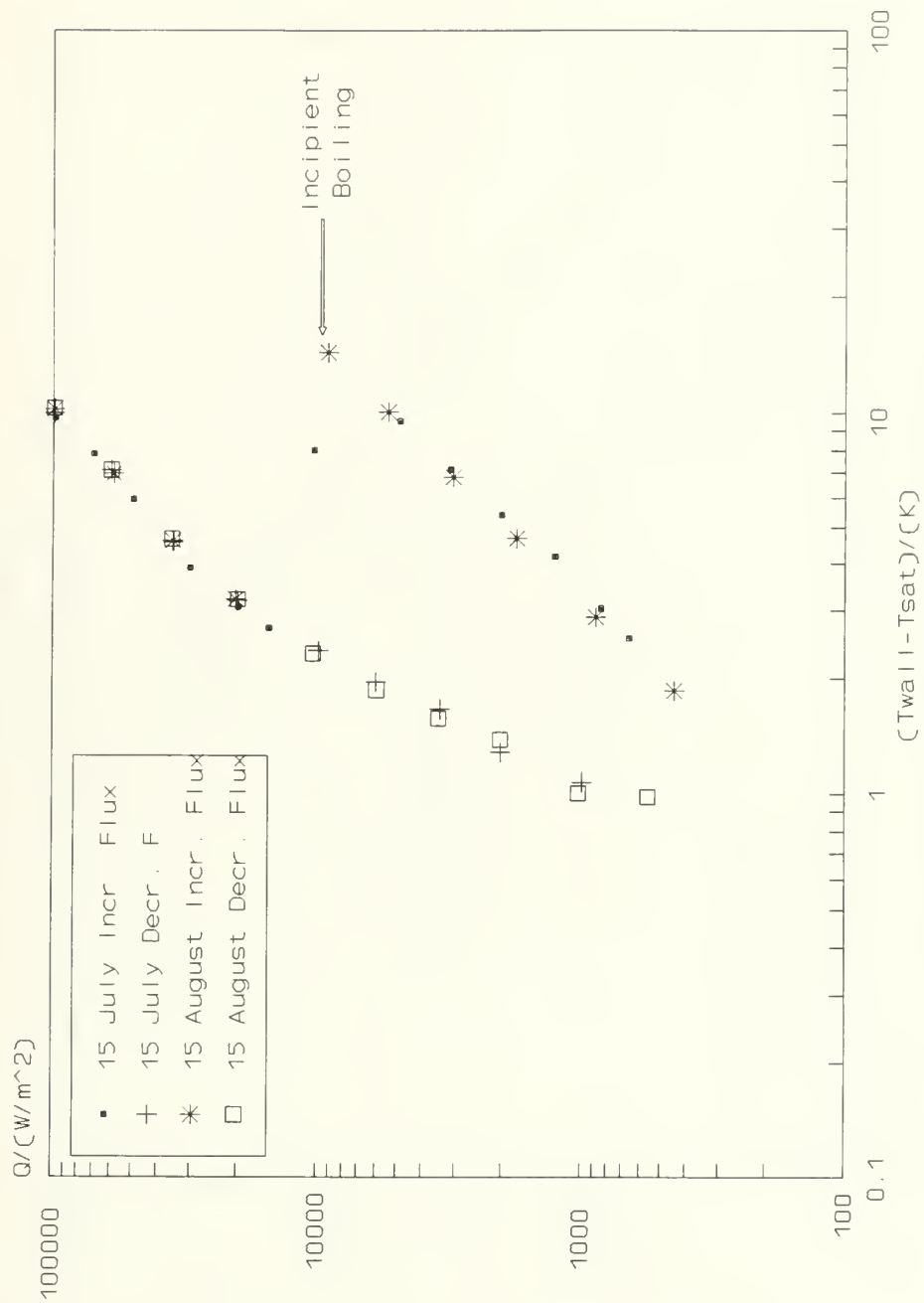
Figure 6.1 Repeatability Comparison For
Pure R-114 Boiling From
GEWA-T 19 fpi Tube
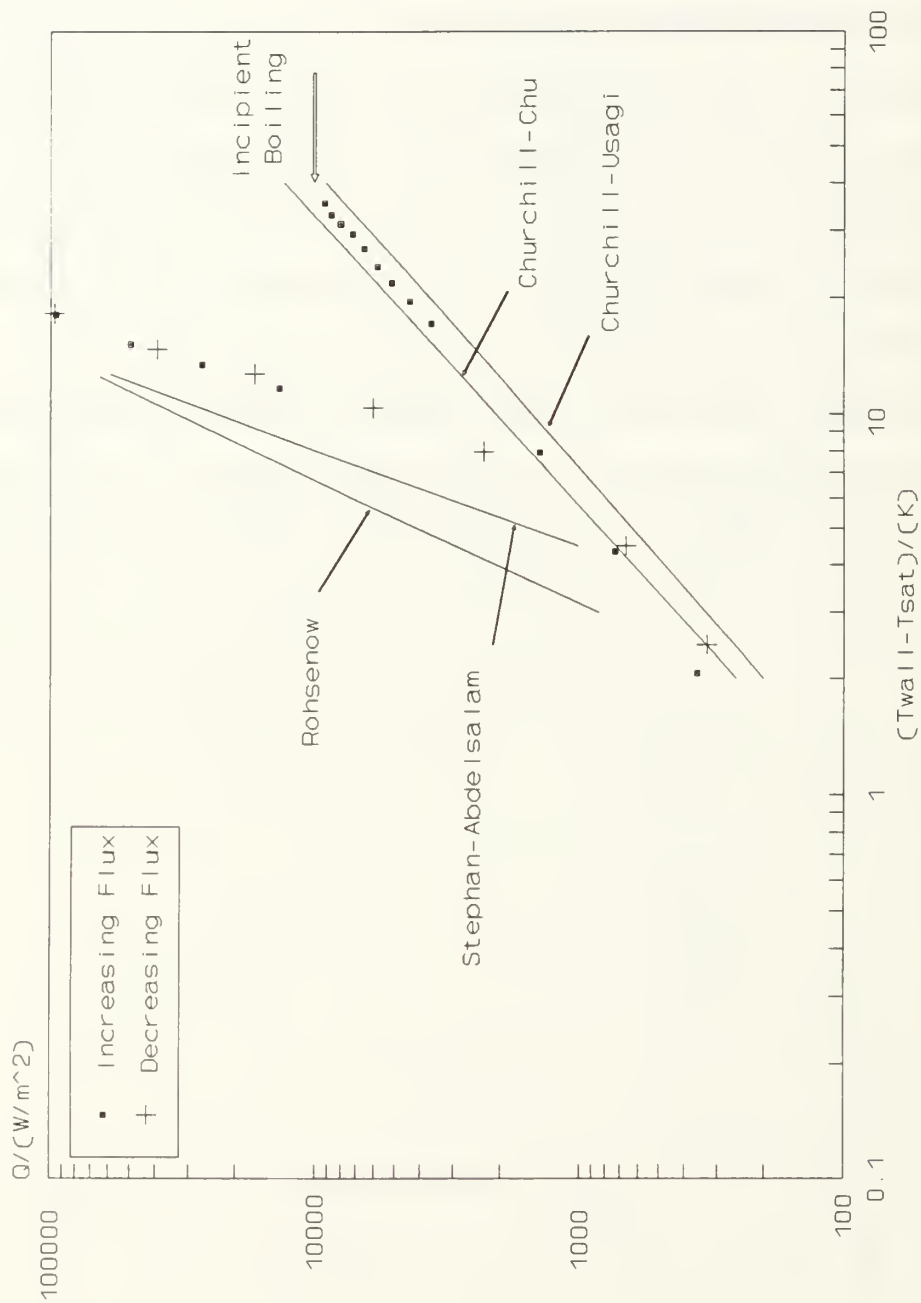
Figure 6.2 Performance Comparison for
Pure R-114 Boiling from a Smooth Tube
With Known Correlations
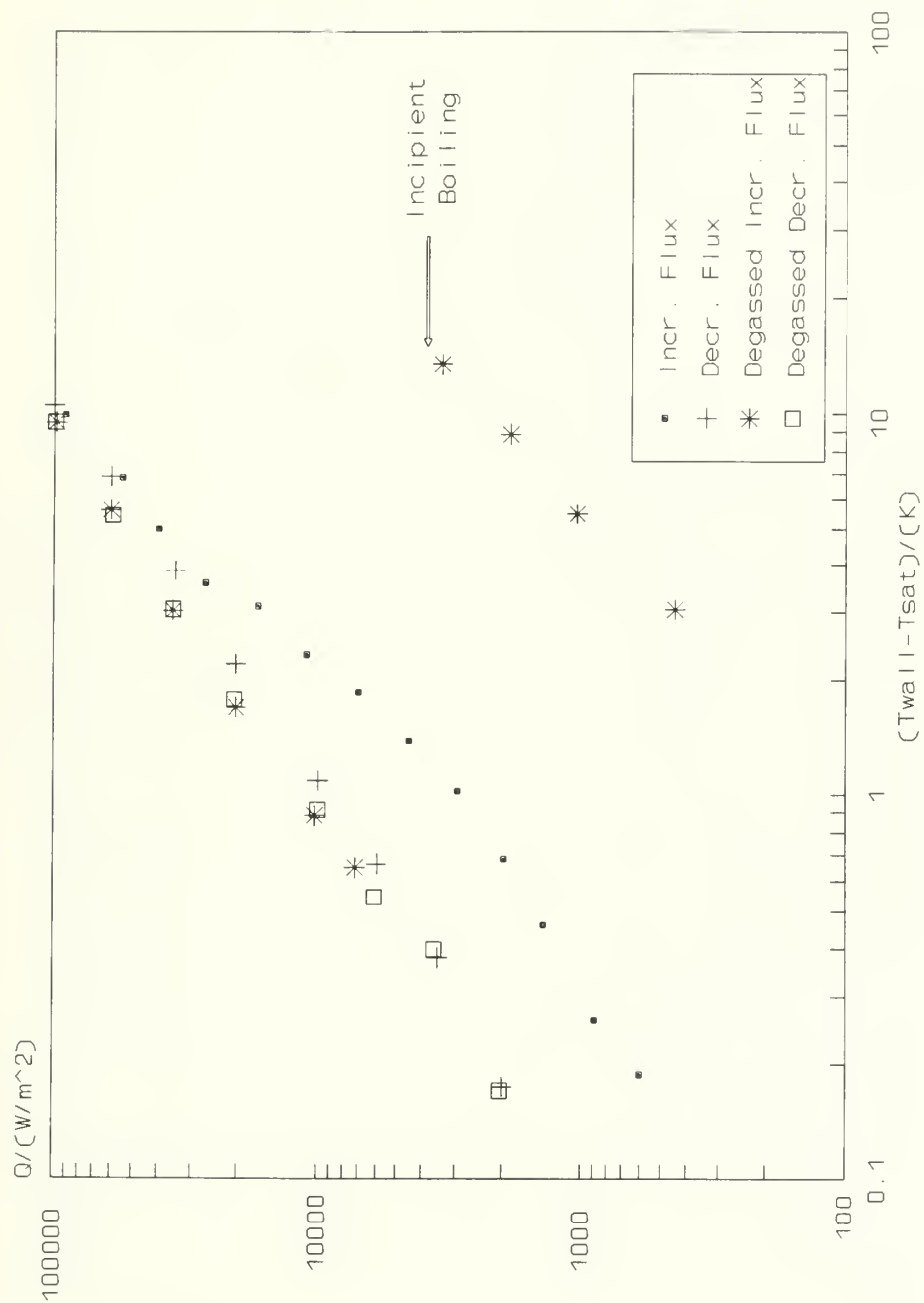
Figure 6.3 Performance Comparison For
Pure R-114 Boiling From Thermoexcel-E
Effect of De-gassing Surface/Fluid

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Figure 6.4 Performance Comparison for
Pure R-114 Boiling From
Smooth Tube Surface
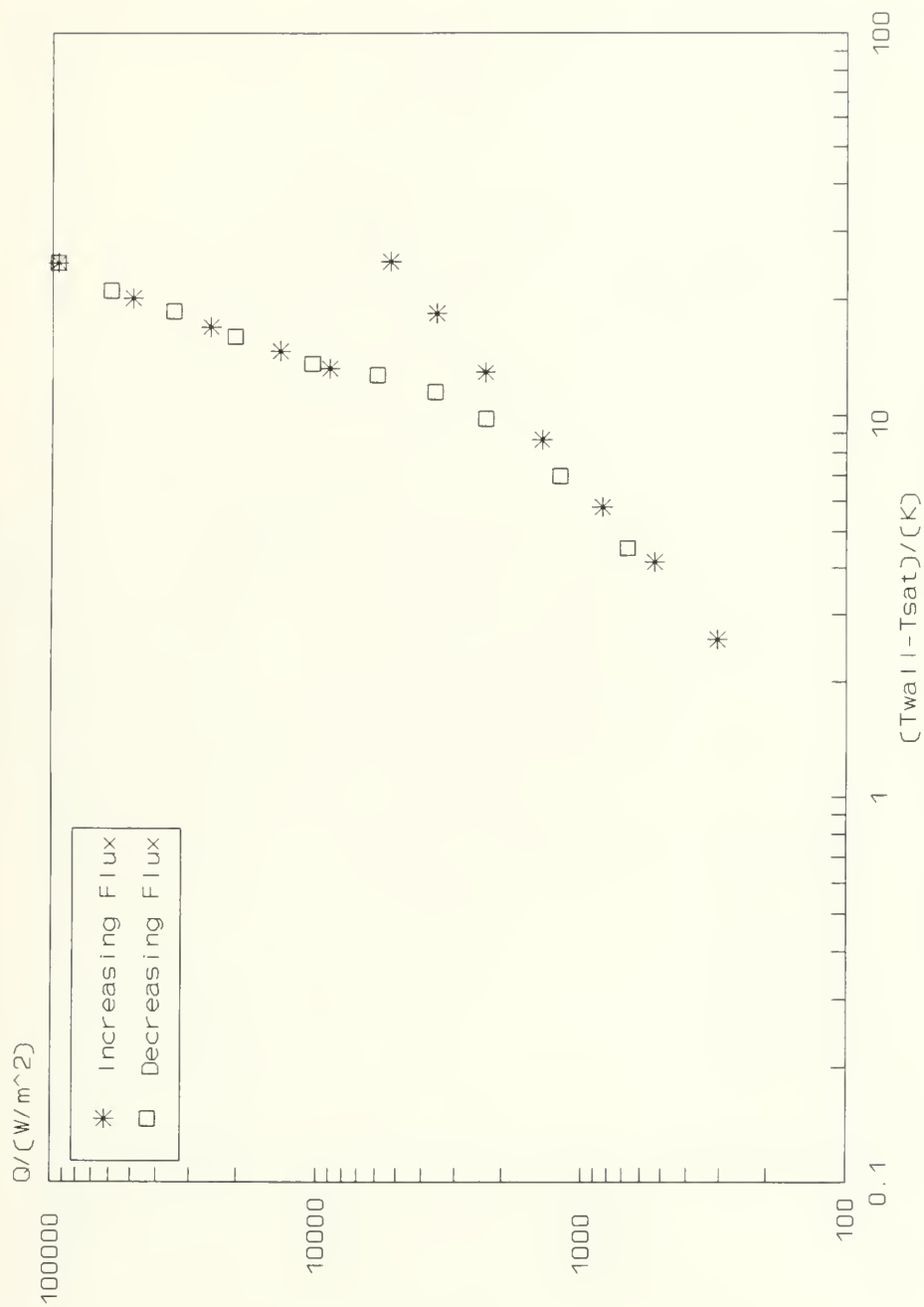
Figure 6.5 Performance Comparison for
R-114/ 3% Oil Mixture Boiling From
Smooth Tube Surface

61
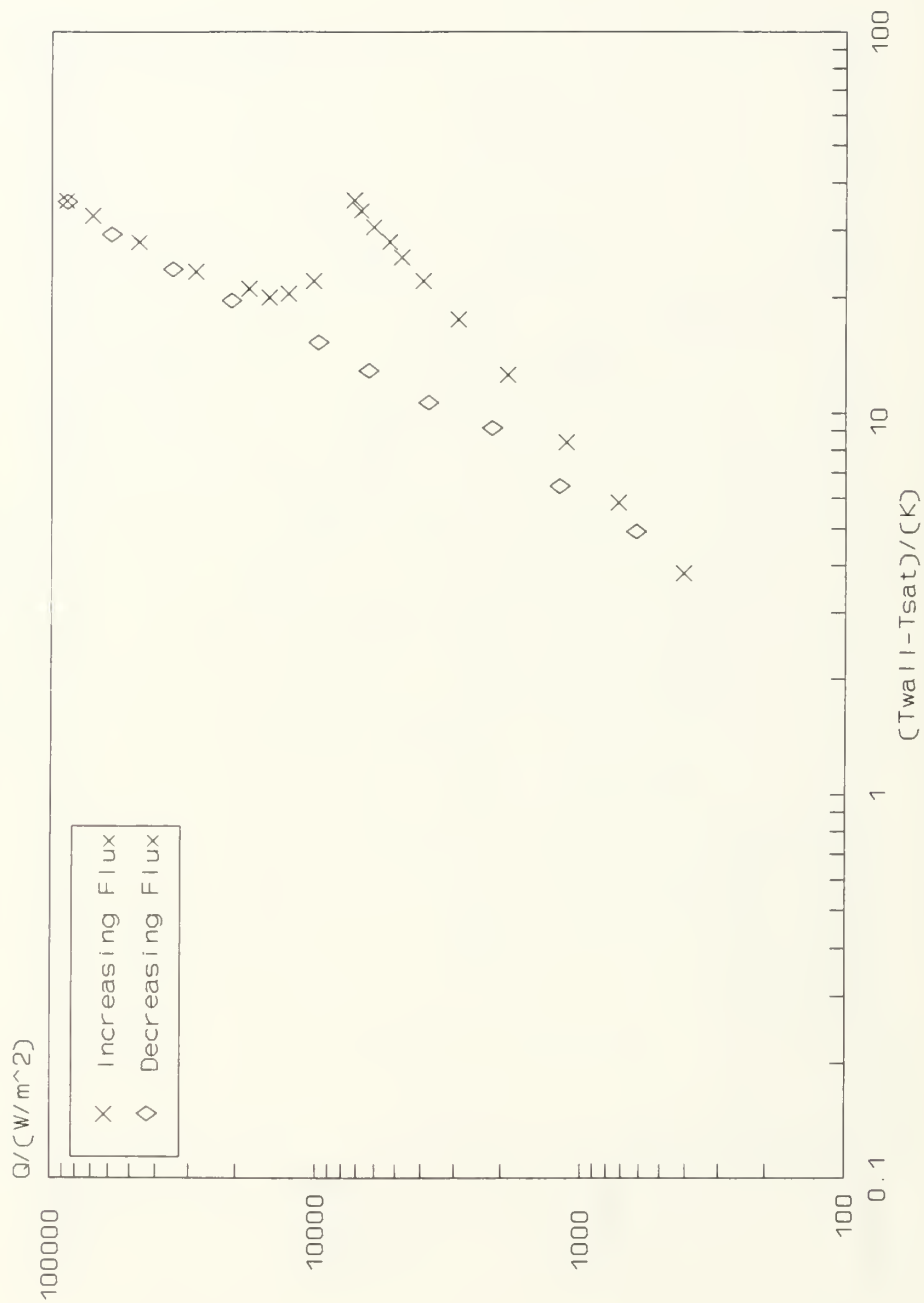
Figure 6.6 Performance Comparison for
Pure R-114/10% Oil Mixture Boiling From
Smooth Tube Surface

62
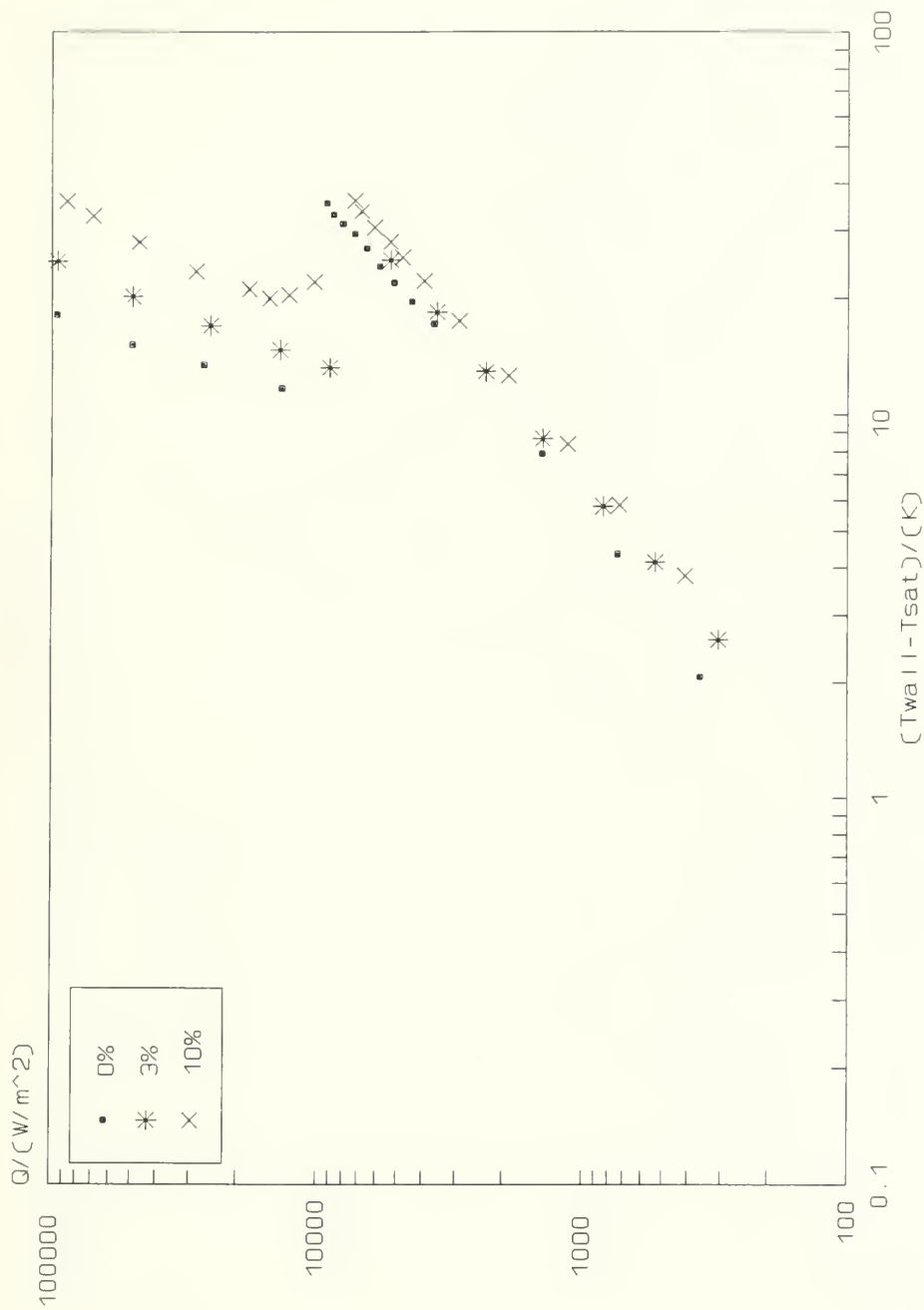
Figure 6.7 Performance Comparison for
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Smooth Tube

63
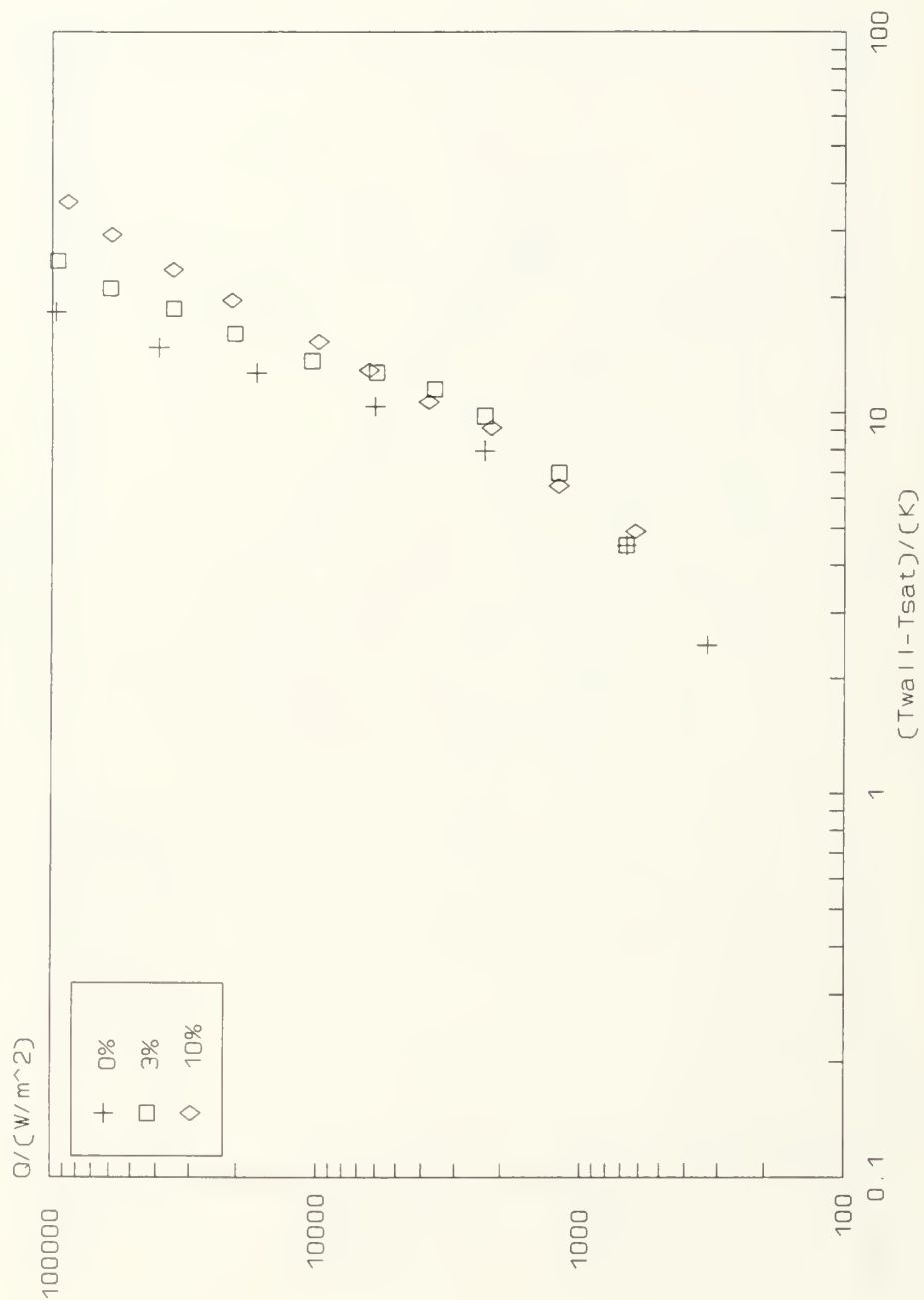
Figure 6.8 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Smooth Tube Surface
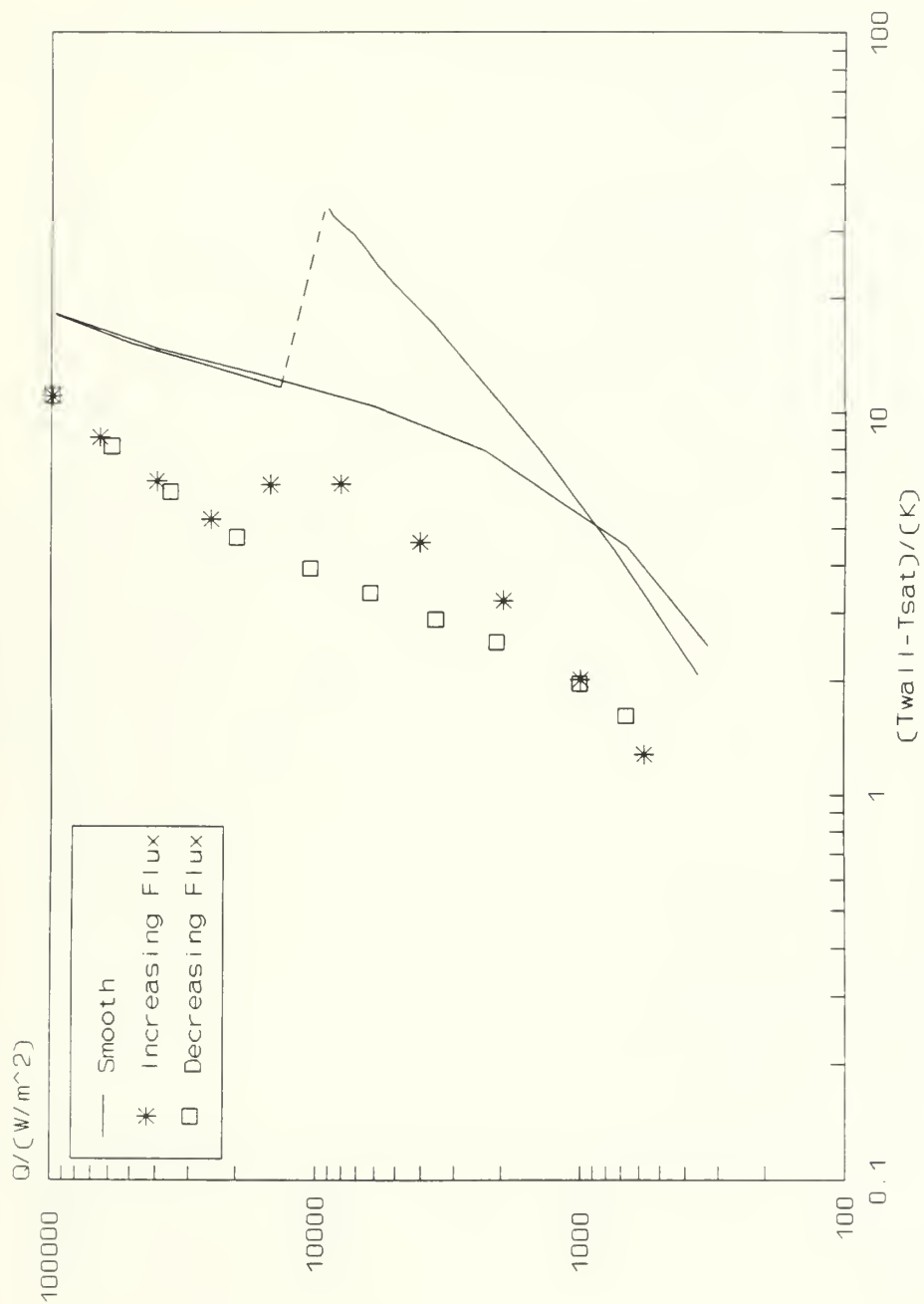
Figure 6.9 Performance Comparison For
Pure R-114 Boiling From
GEWA-K 26 fpi Tube

65
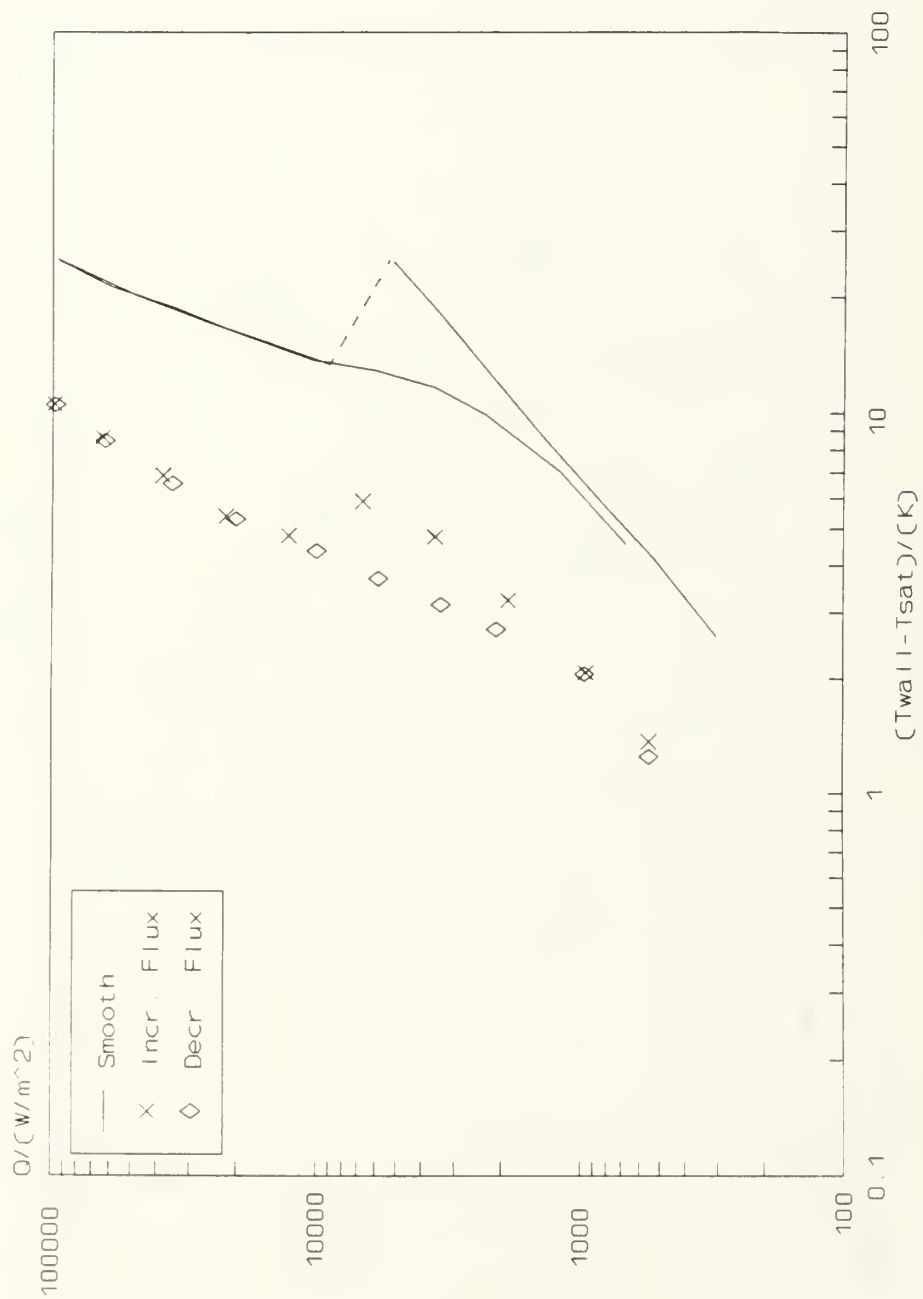
Figure 6.10 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-K 26 fpi Tube

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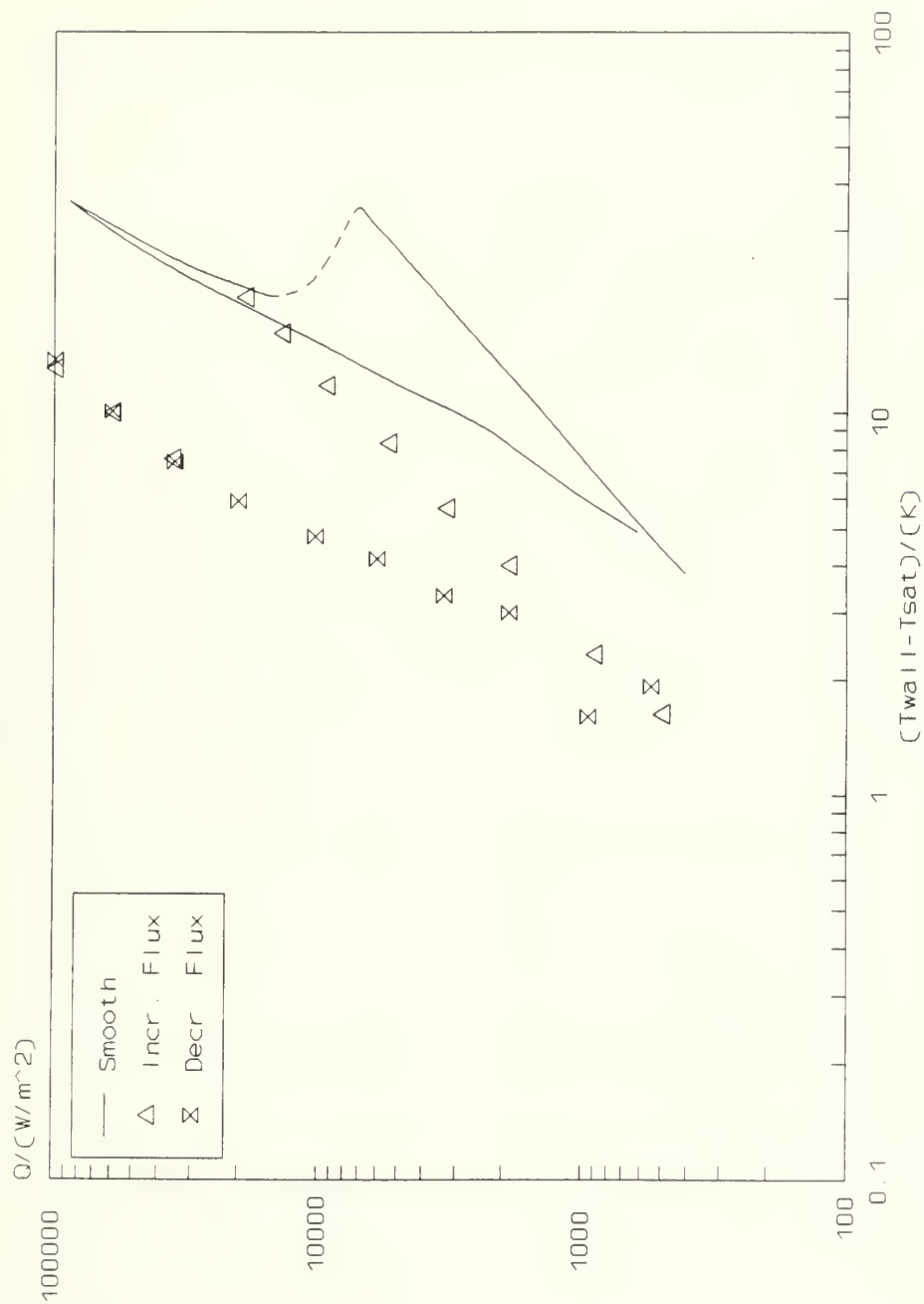
Figure 6.11 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-K 26 fpi Tube

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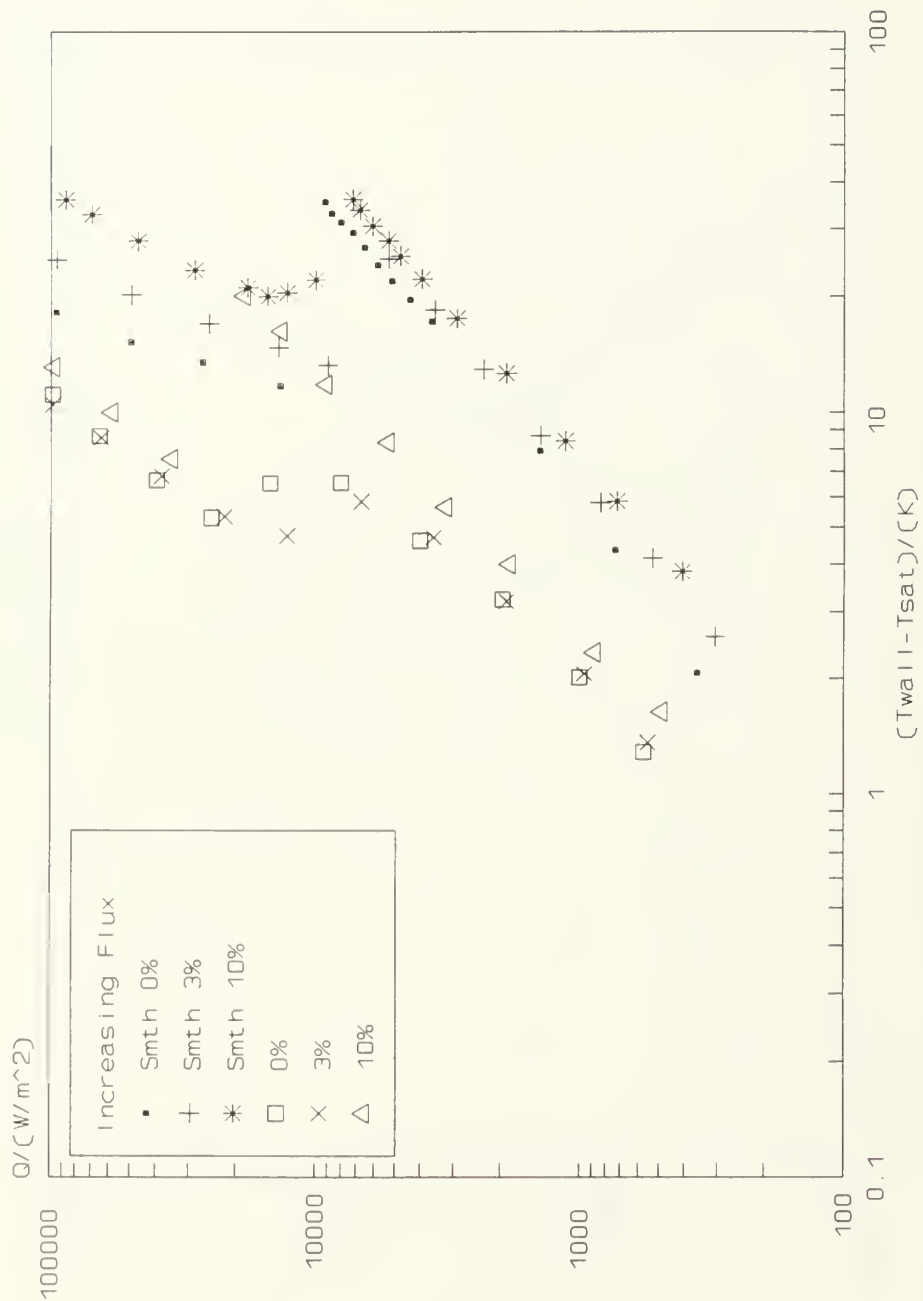
Figure 6.12 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 26 fpi Tube

68
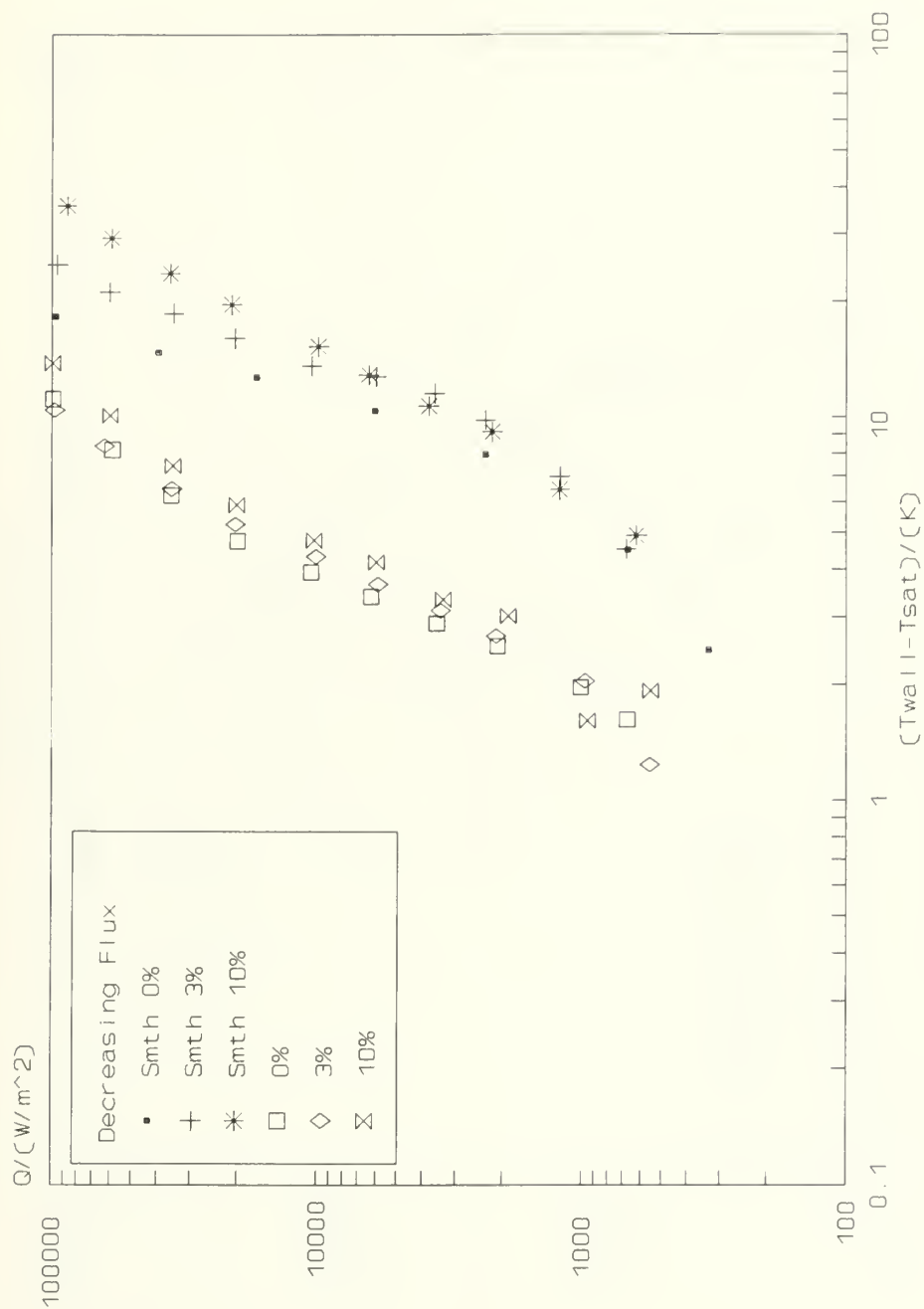
Figure 6.13 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 26 fpi Tube

69
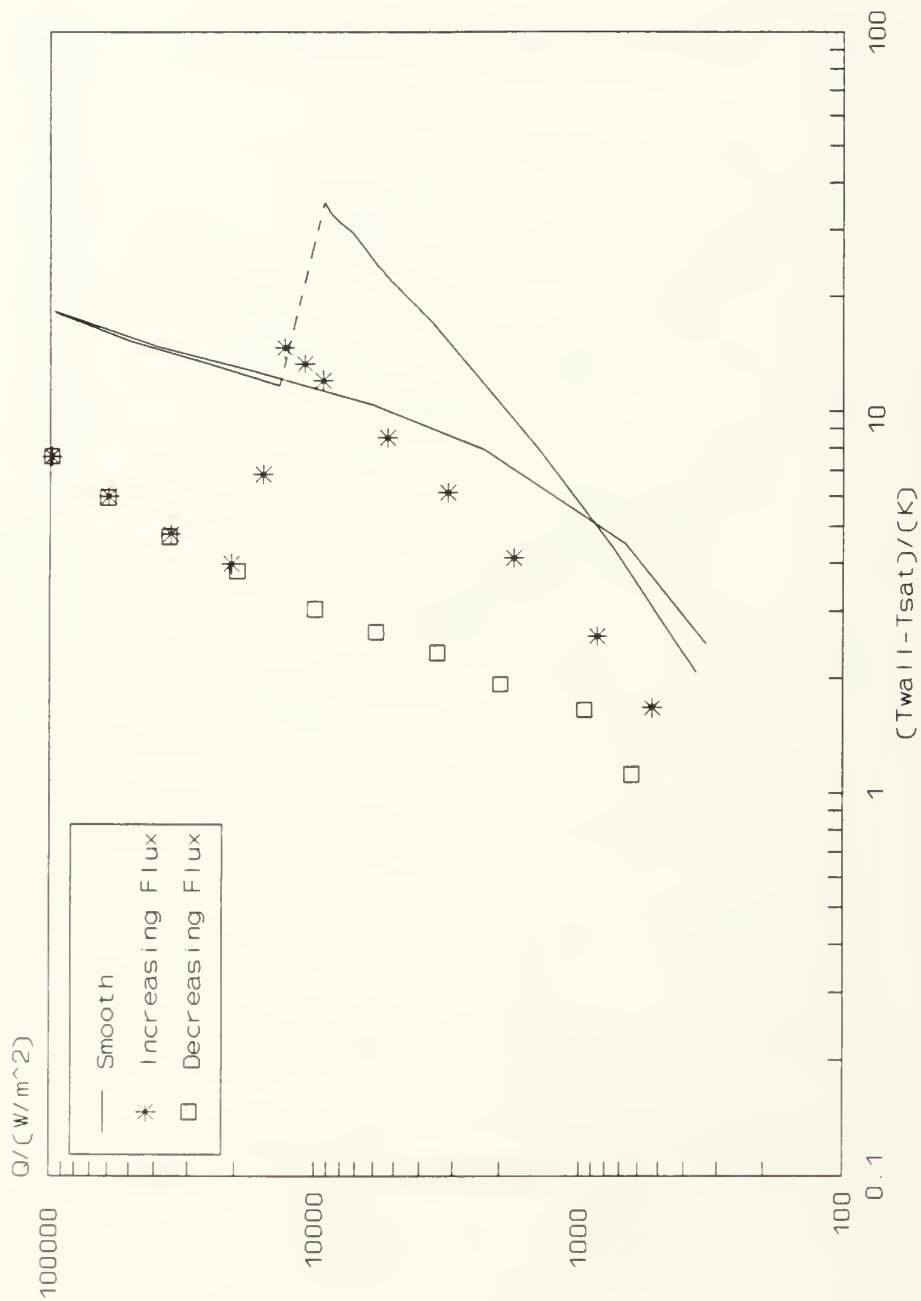
Figure 6.14 Performance Comparison For
Pure R-114 Boiling From
GEWA-K 40 fpi Tube
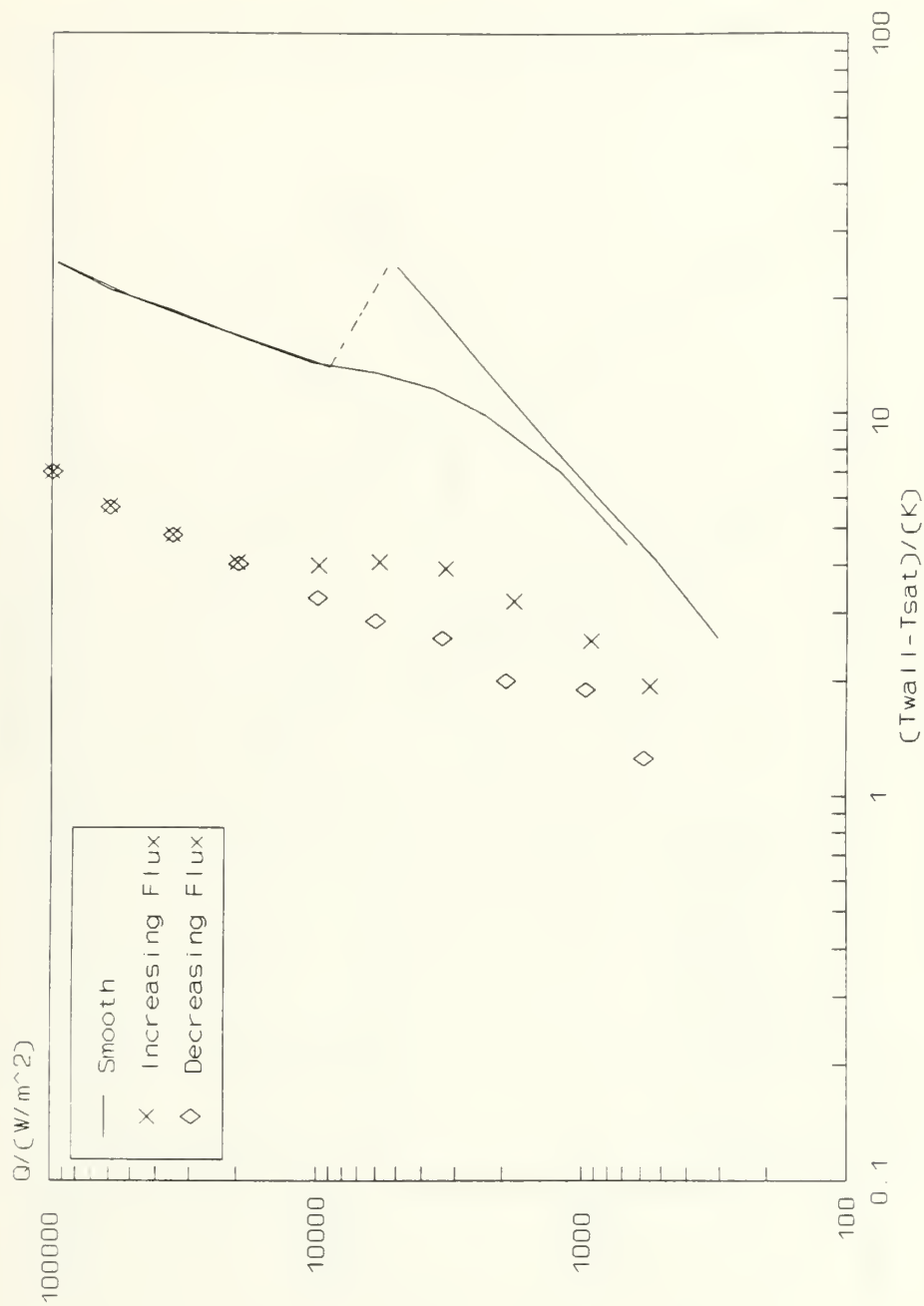
Figure 6.15 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-K 40 fpi Tube

71
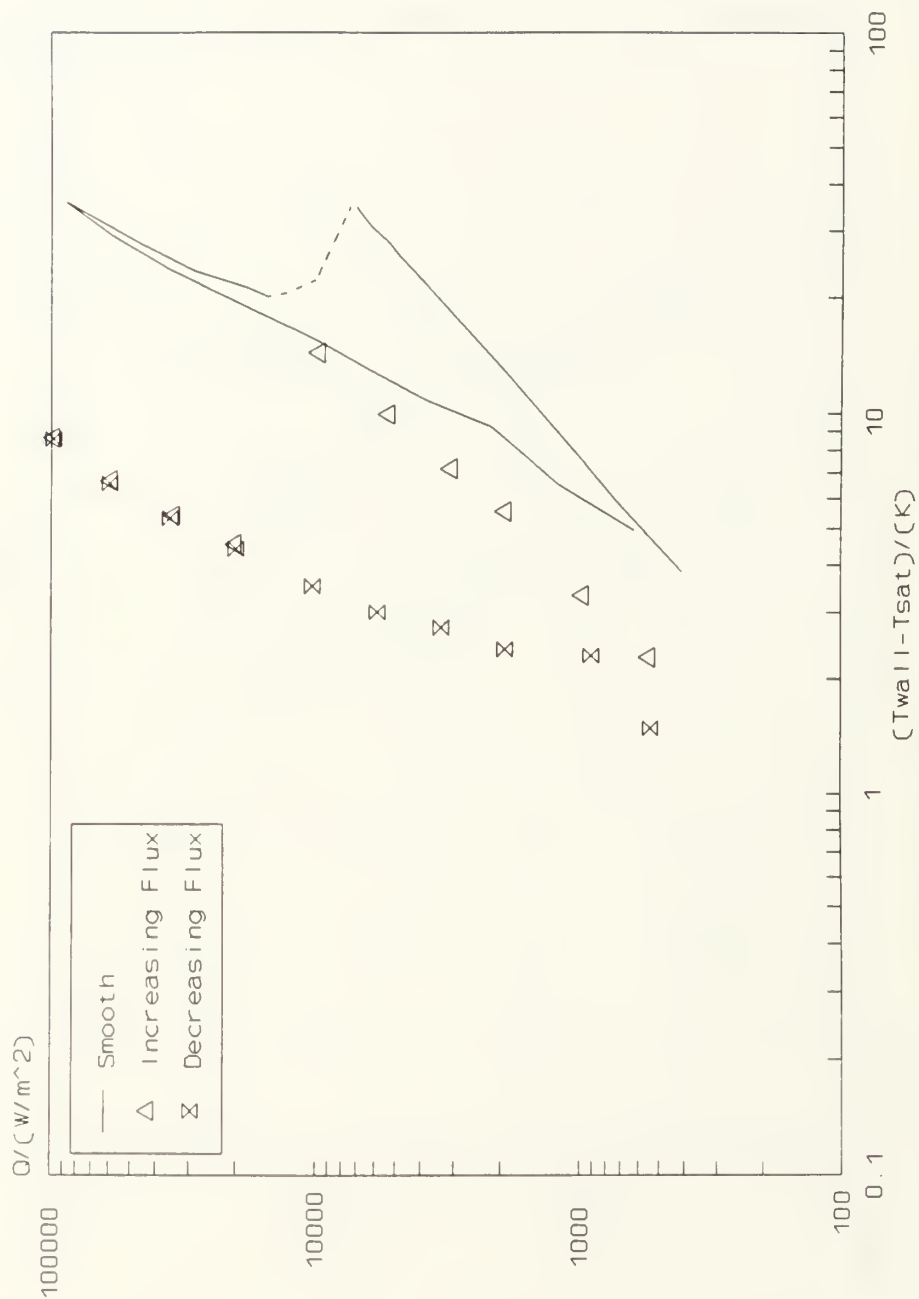
Figure 6-16 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-K 40 fpi Tube

72
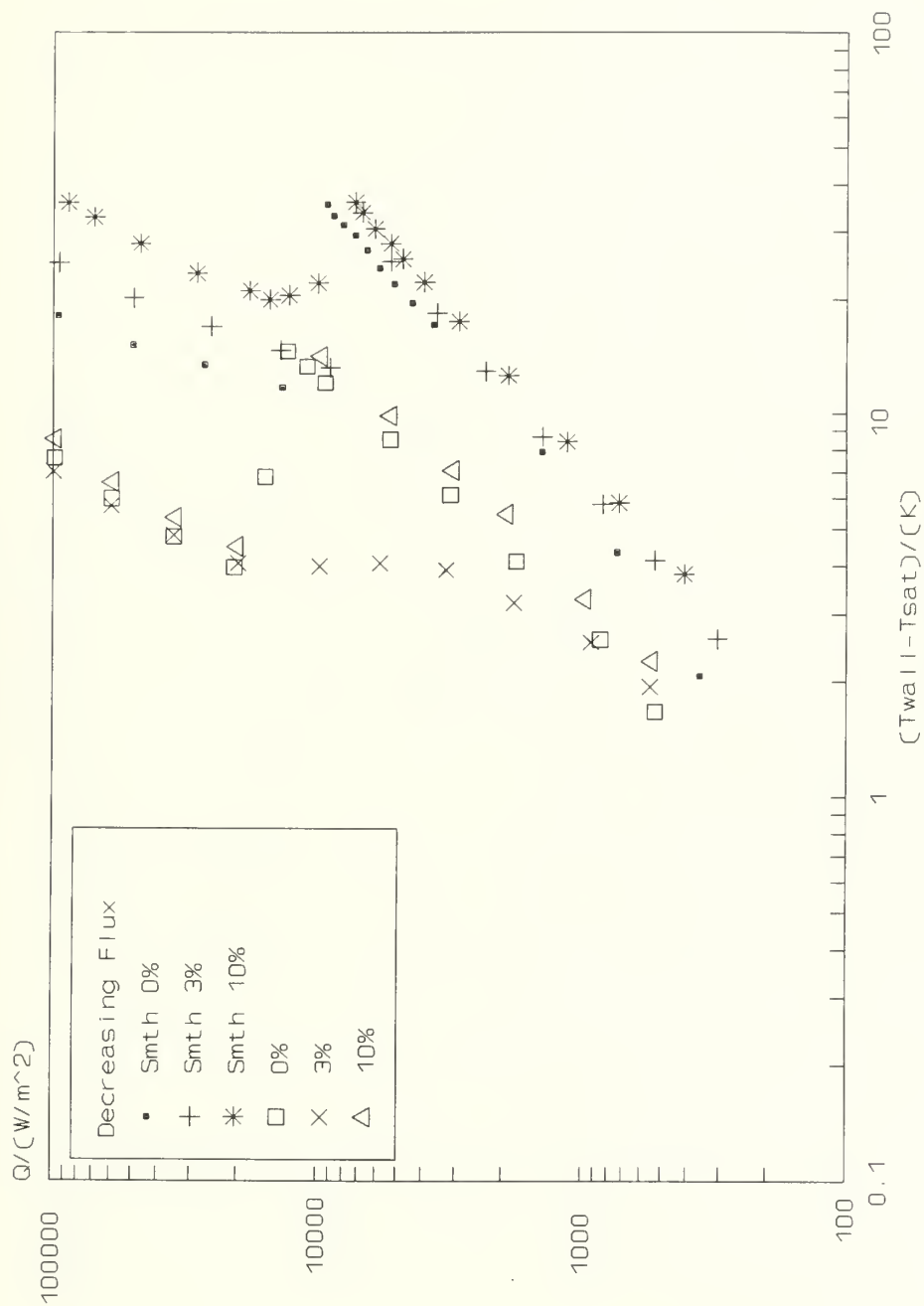
Figure 6.17 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-K 40 fpi Tube

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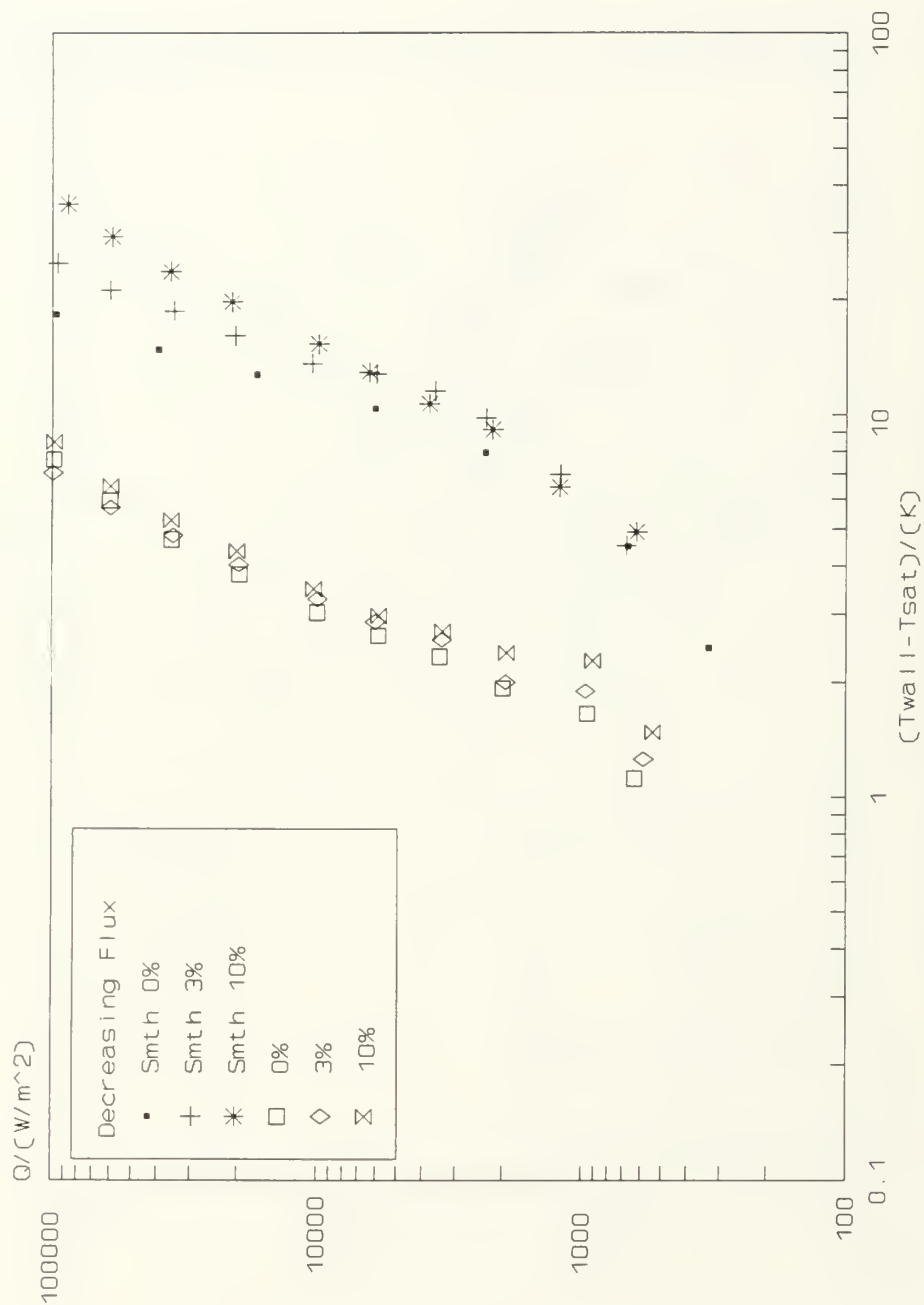
Figure 6.18 Performance Comparison For
Boiling R-114/0%, 3% & 10% Oil Mixtures
From GEWA-K 40 fpi Tube

74
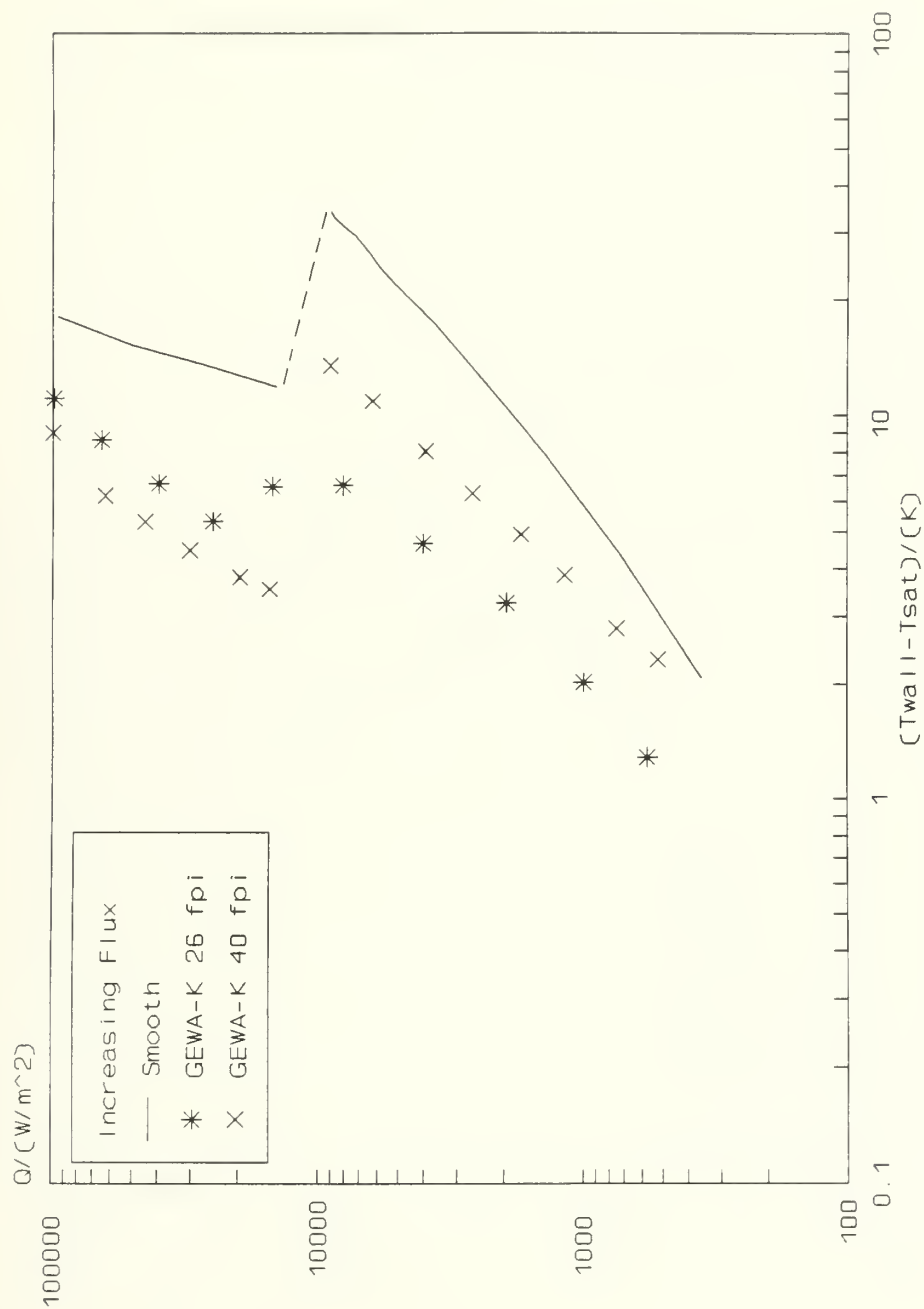
Figure 6.19 Performance Comparison For
Boiling Pure R-114 From
GEWA-K 26/40 fpi Tubes

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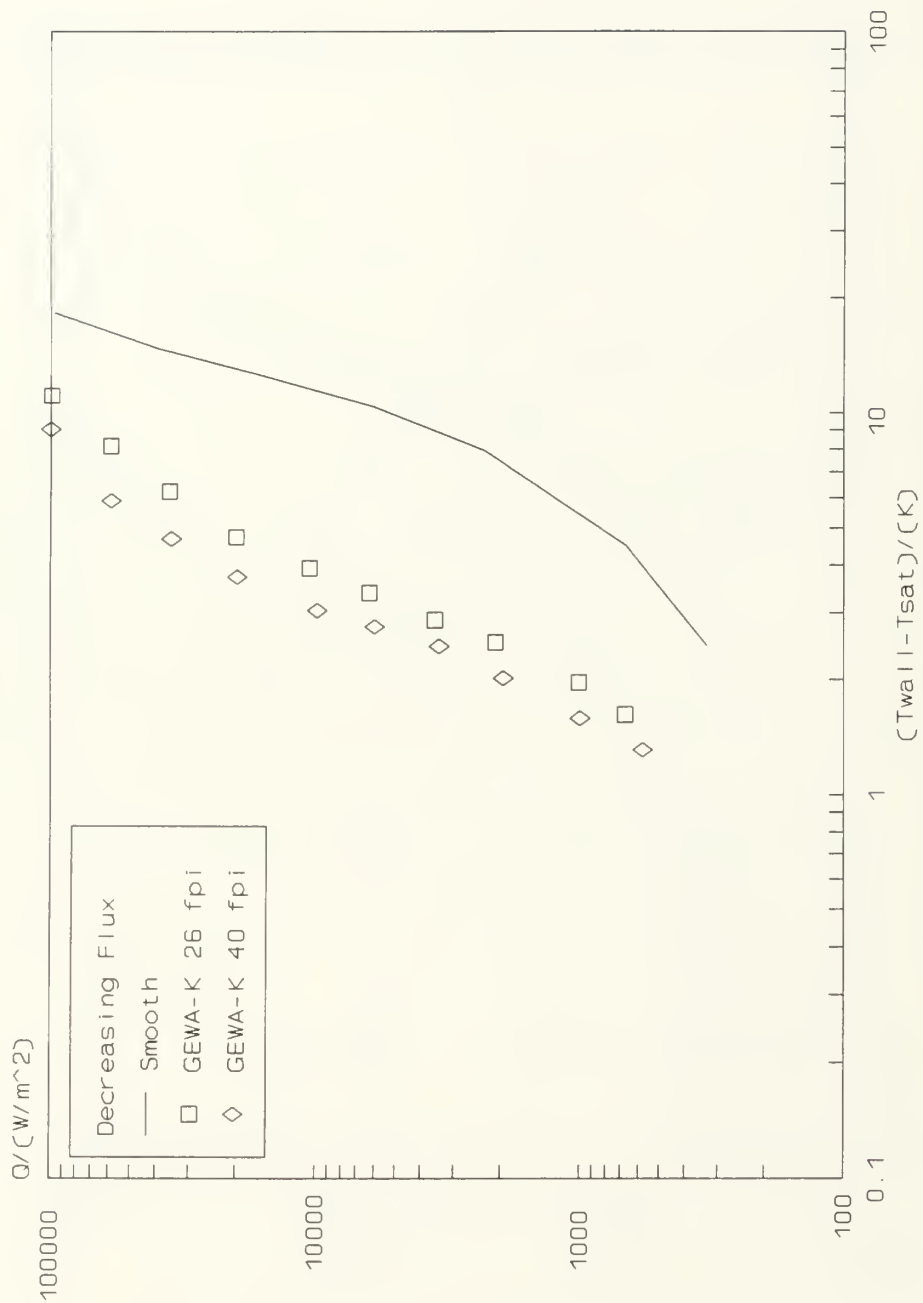
Figure 6.20 Performance Comparison For
Boiling Pure R-114 From
GEWA-K 26/40 fpi Tubes

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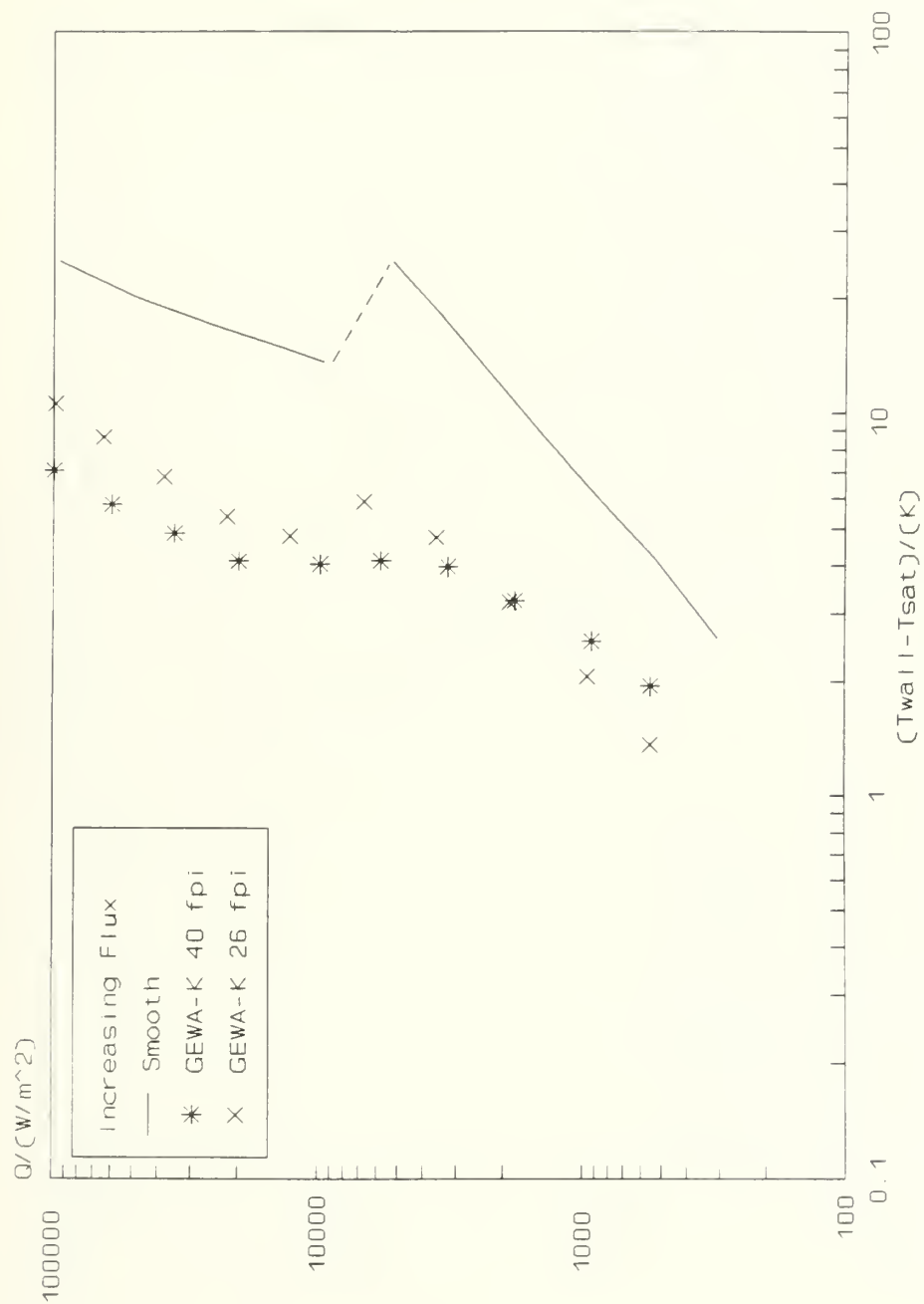
Figure 6.21 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-K 26/40 fpi Tubes

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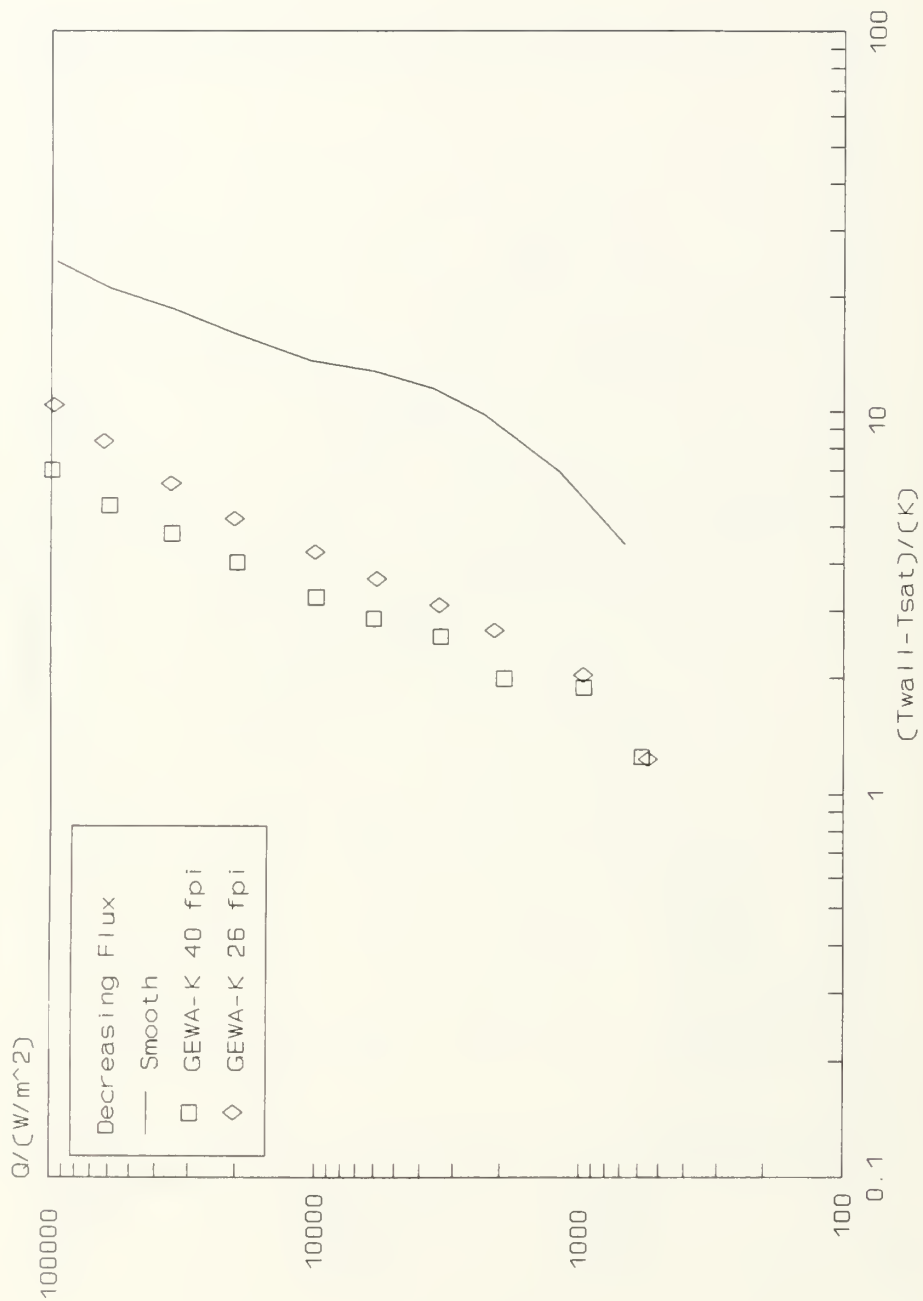
Figure 6.22 Performance Comparison For
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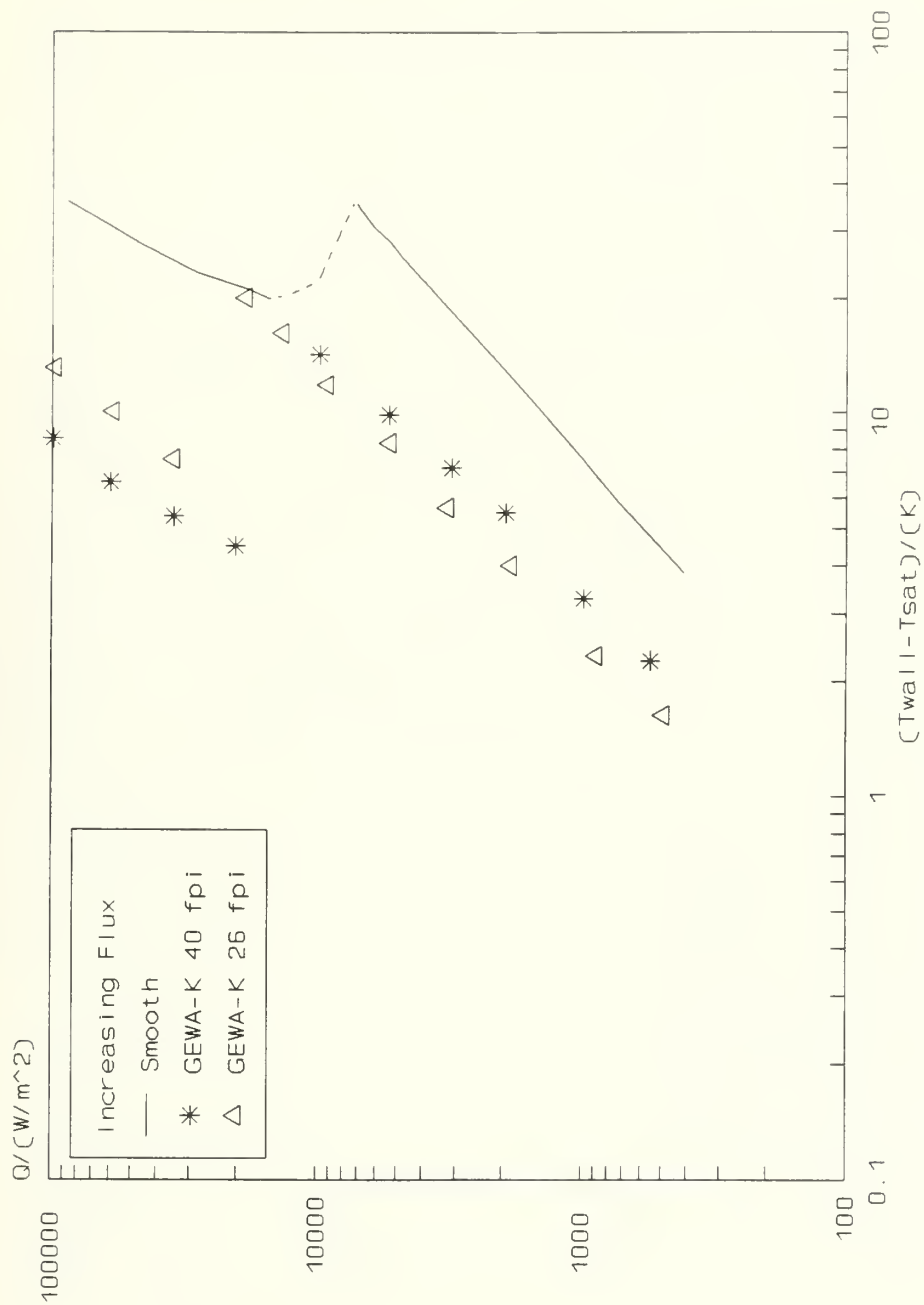
Figure 6.23 Performance Comparison For
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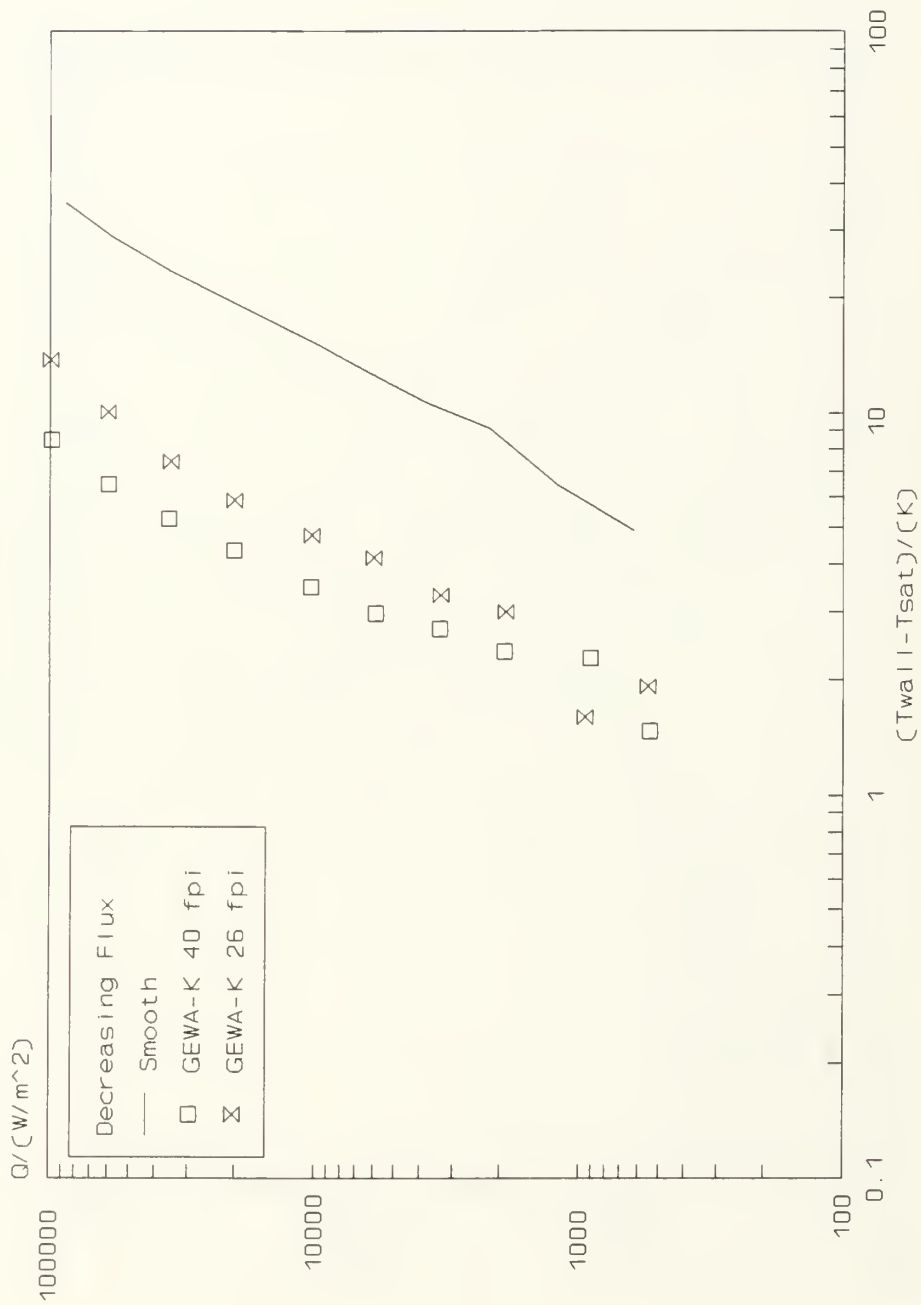
Figure 6.24 Performance Comparison For
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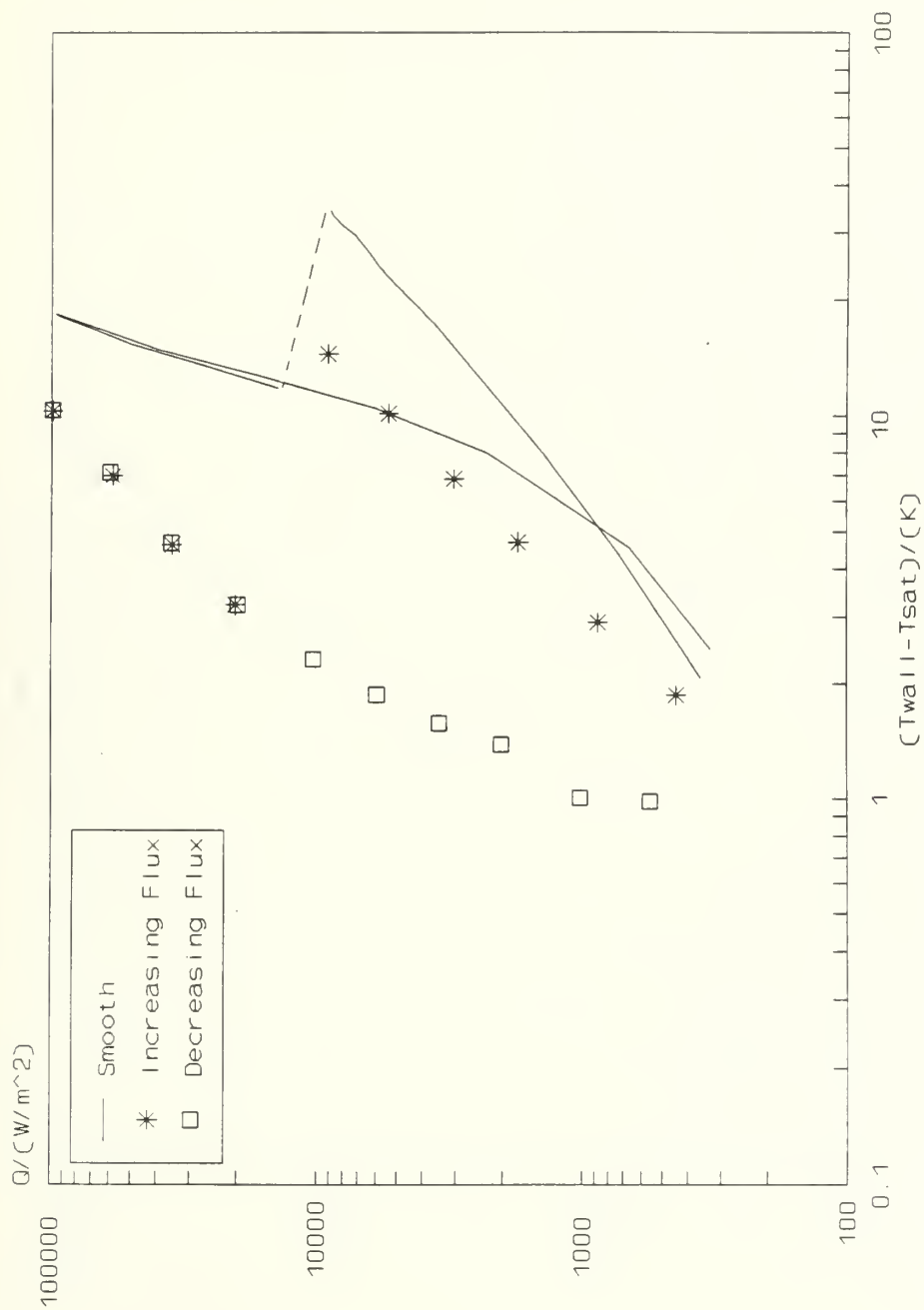
Figure 6.25 Performane Comparison For
Pure R-114 Boiling From
GEWA-T 19 fpi Tube

81
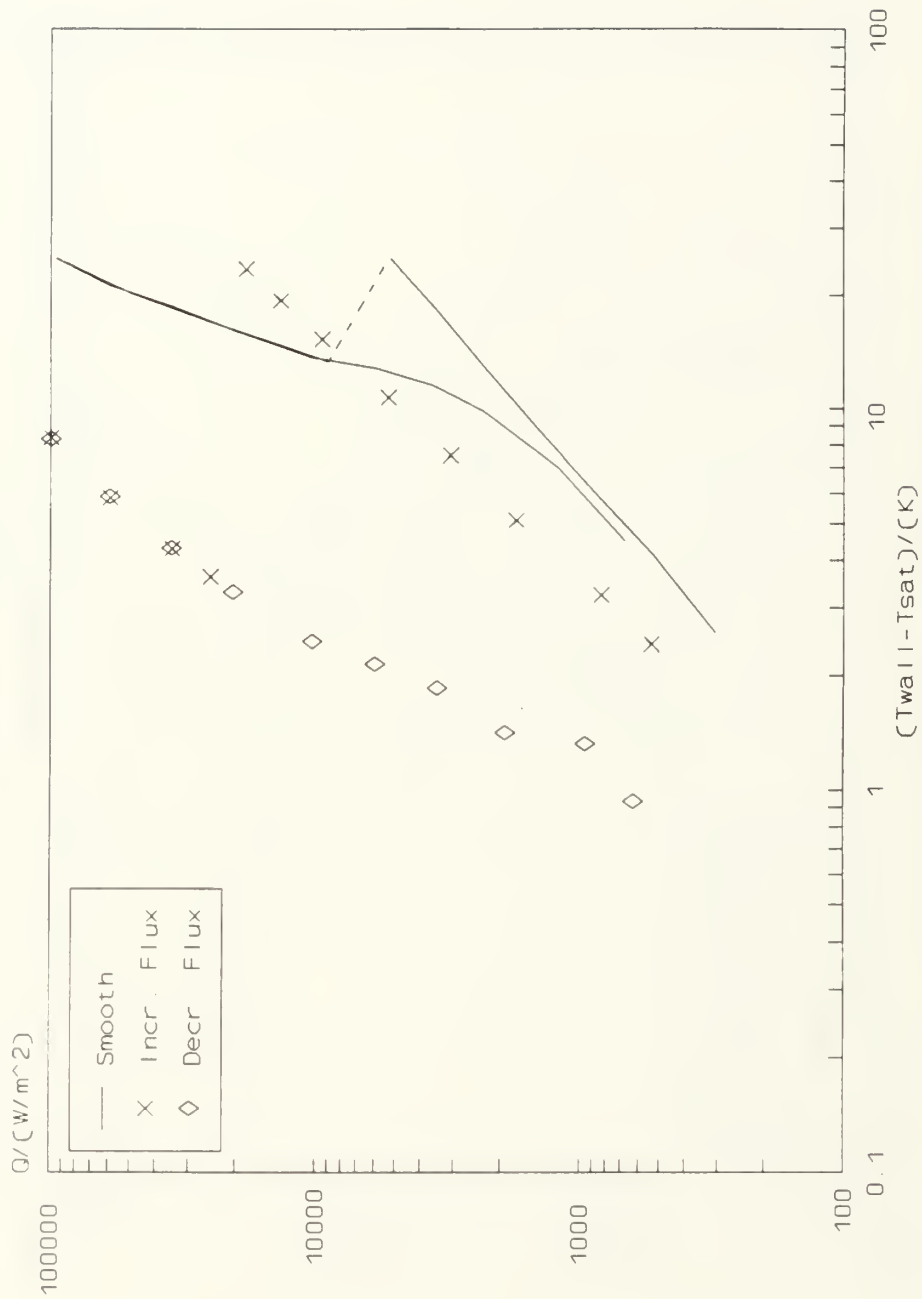
Figure 6.26 Performance Comparison For
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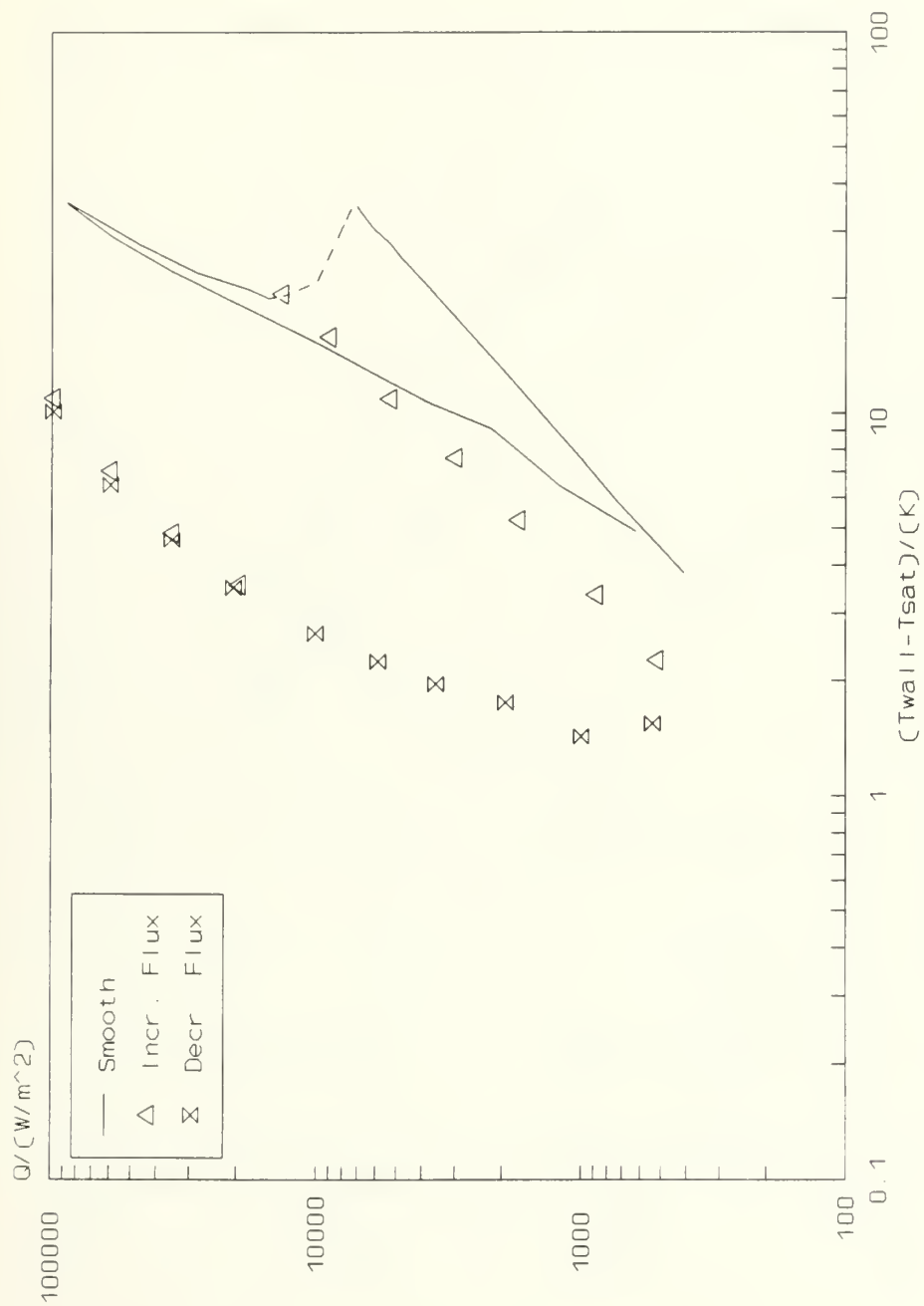
Figure 6.27 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-T 19 fpi Tube

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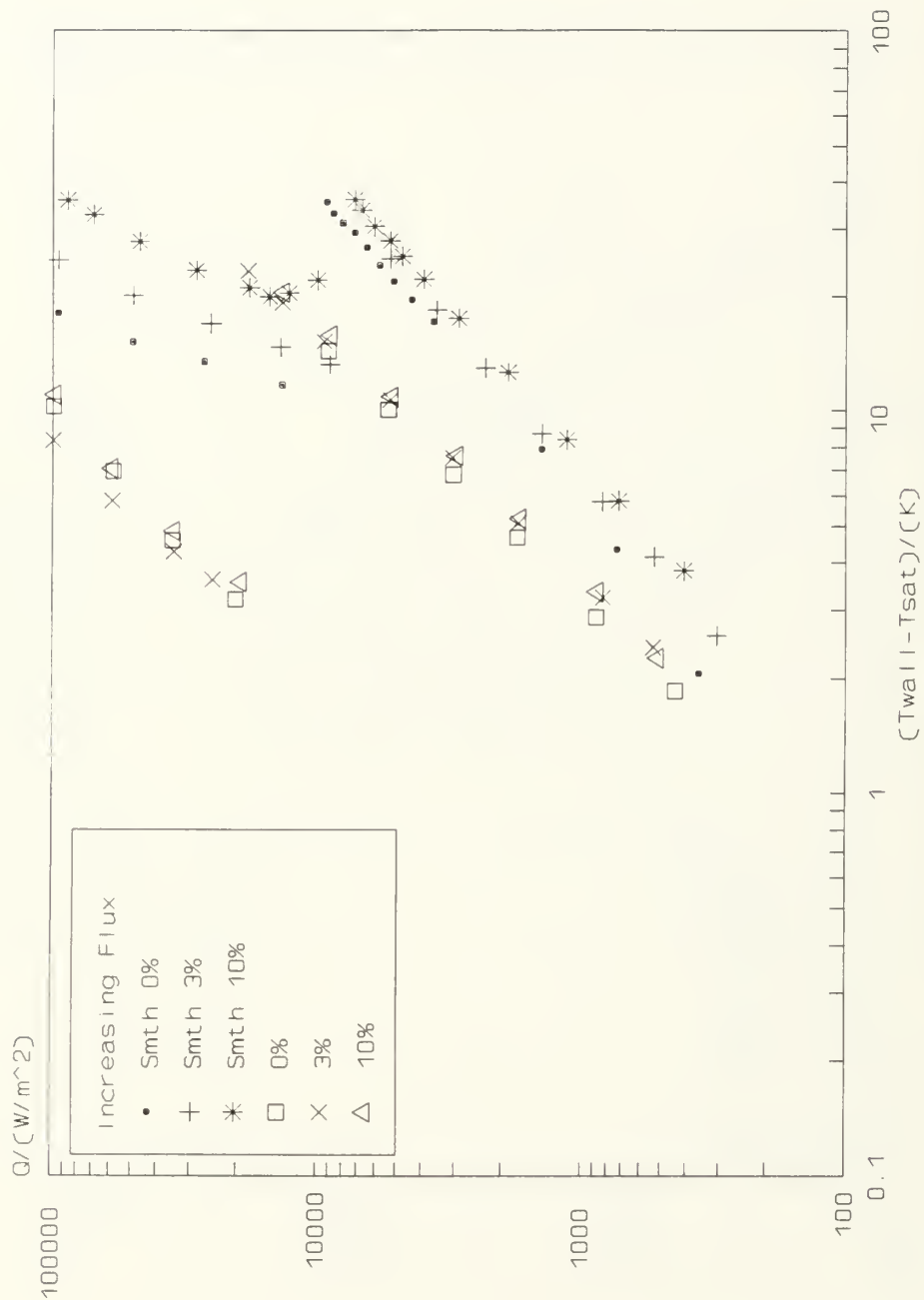
Figure 6.28 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-T 19 fpi Tube

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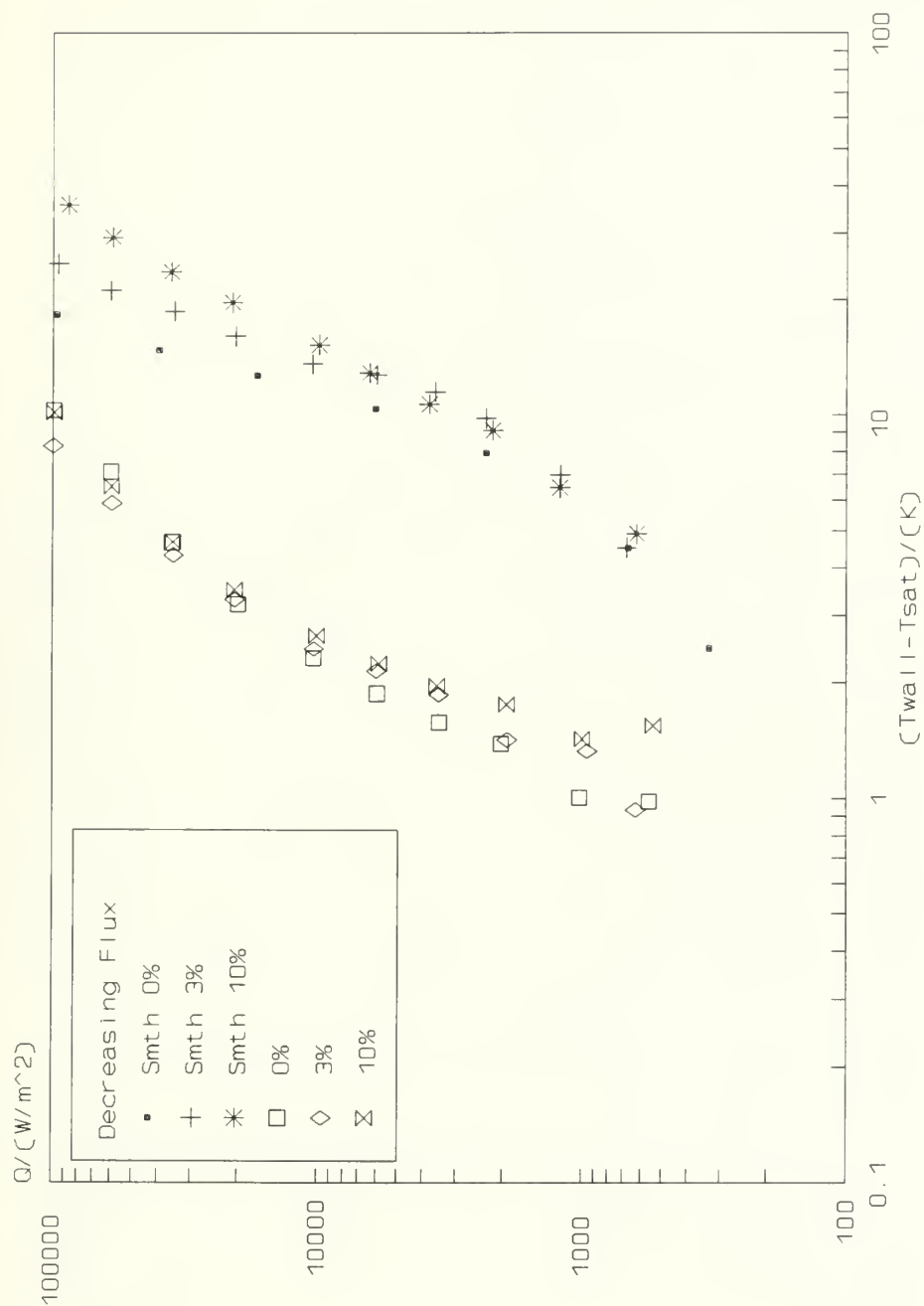
Figure 6.29 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-T 19 fpi Tube

85

Figure 6.30 Performance Comparison For
Pure R-114 Boiling From
GEWA-T 26 fpi Tube

86
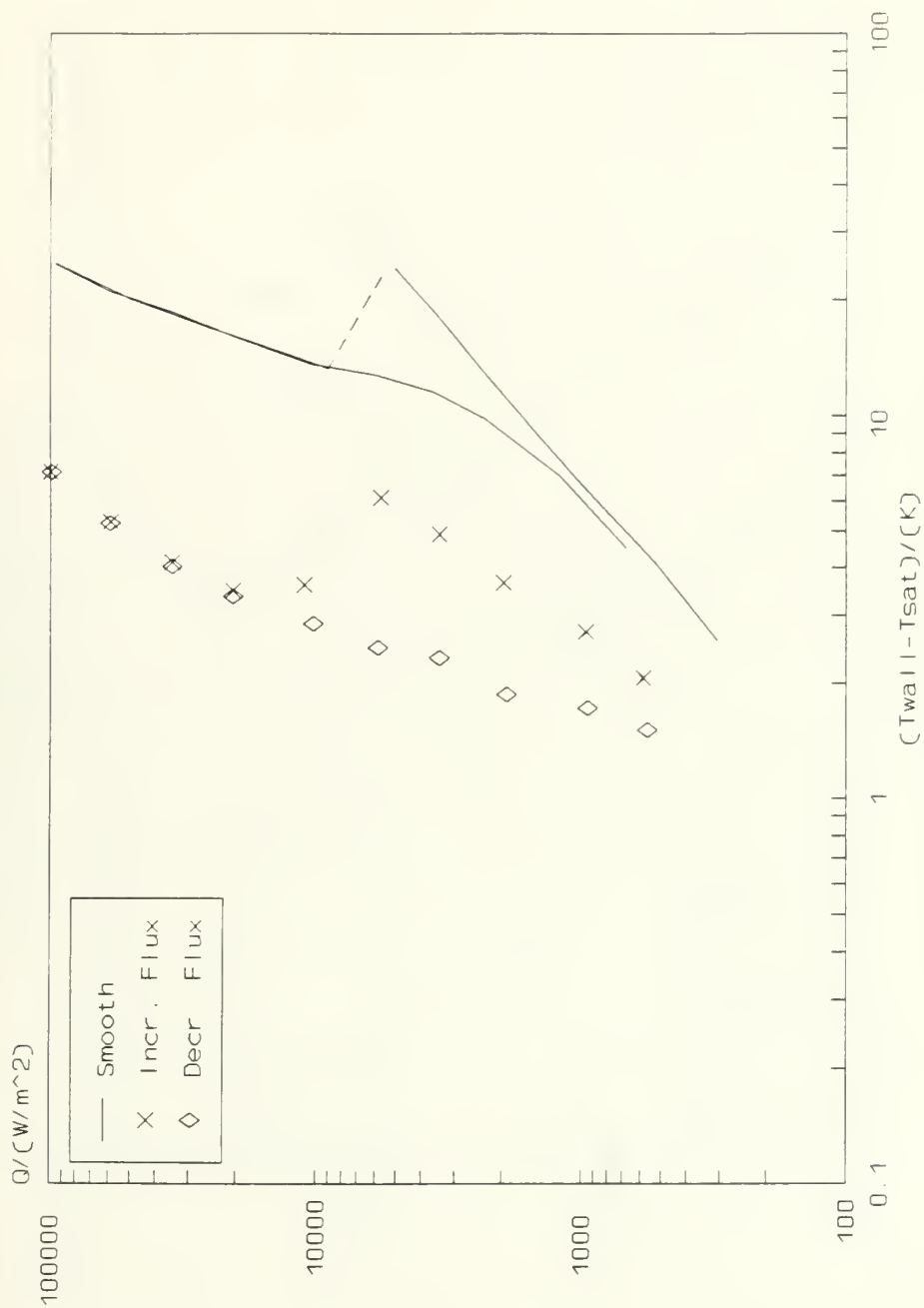
Figure 6.31 Performance Comparison For
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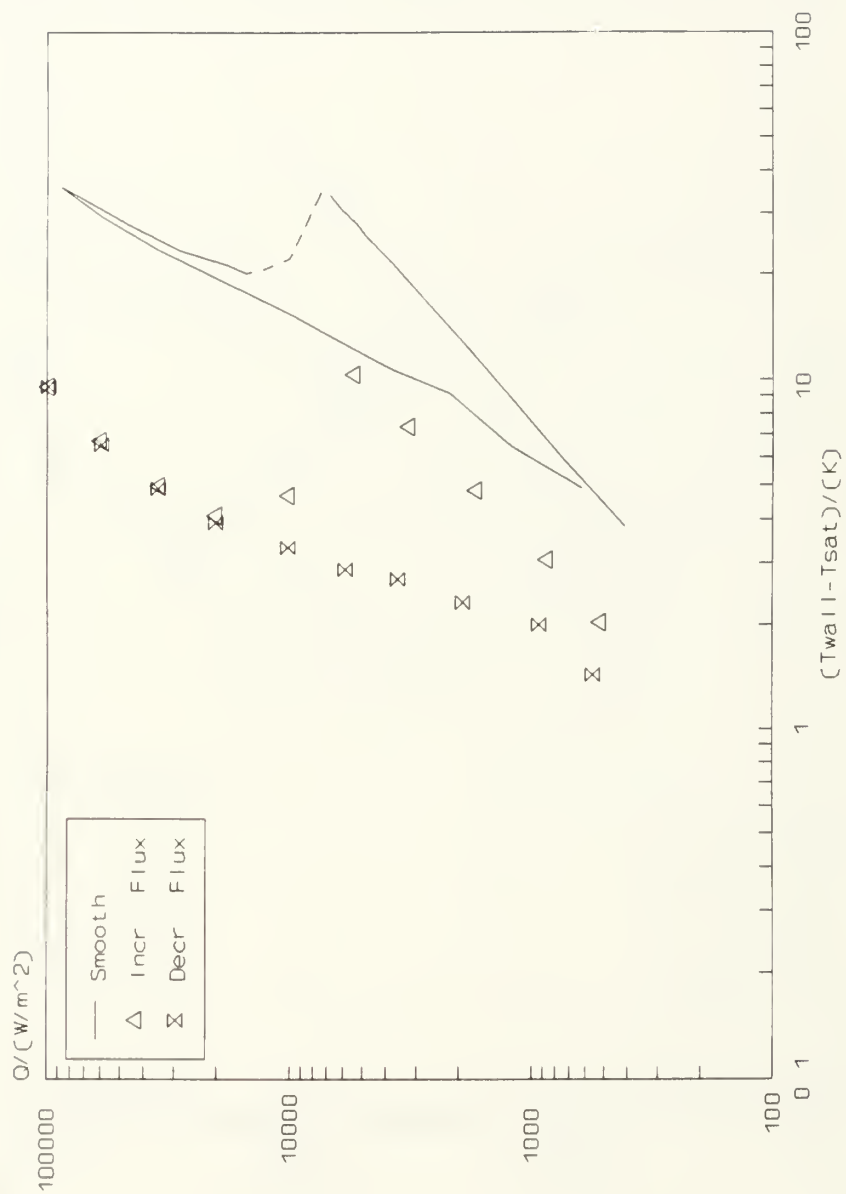
Figure 6.32 Performance Comparison For
Boiling R-114/10% Oil Mixture From
GEWA-T 26 fpi Tube

88
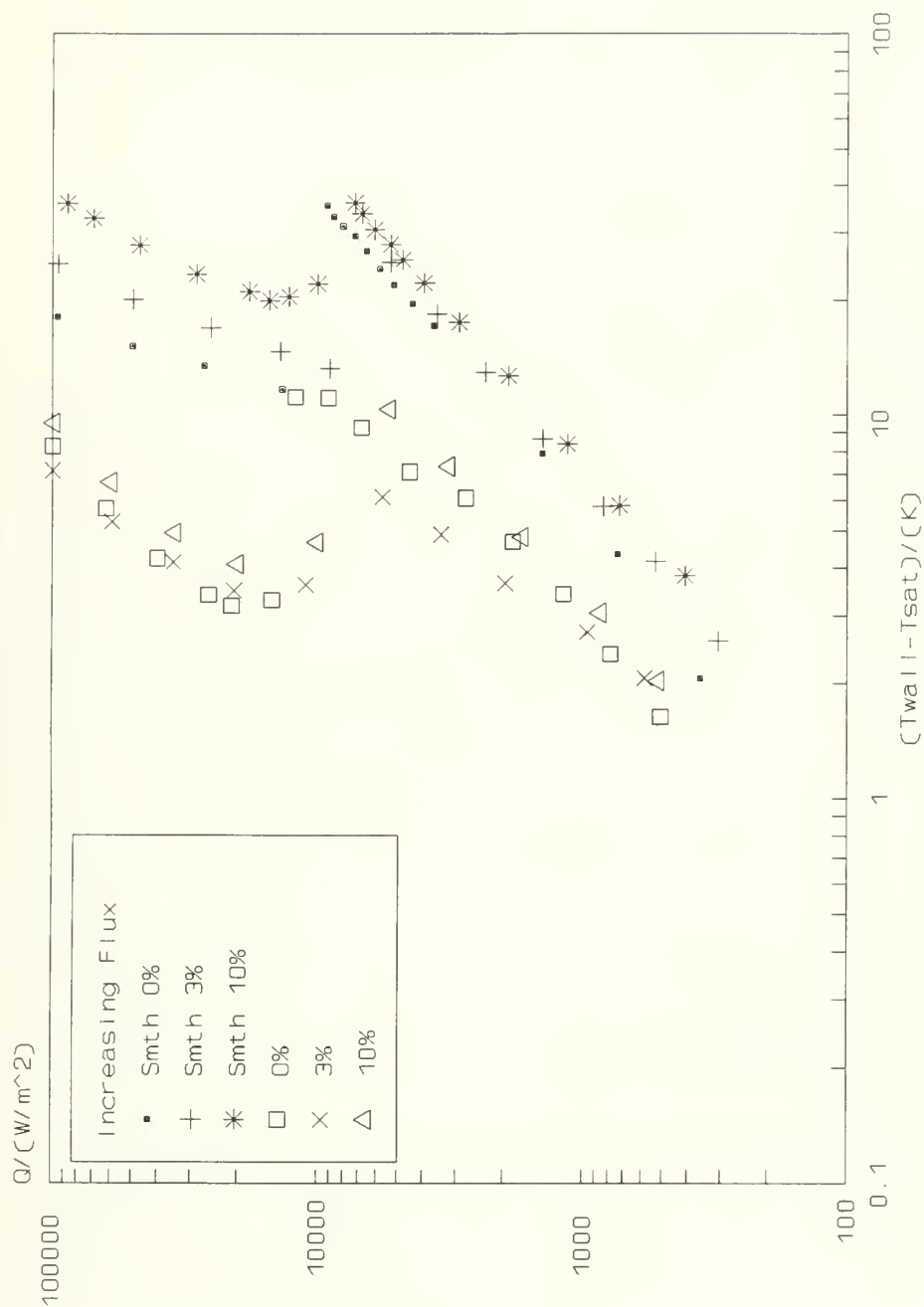
Figure 6.33 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
From GEWA-T 26 fpi Tube

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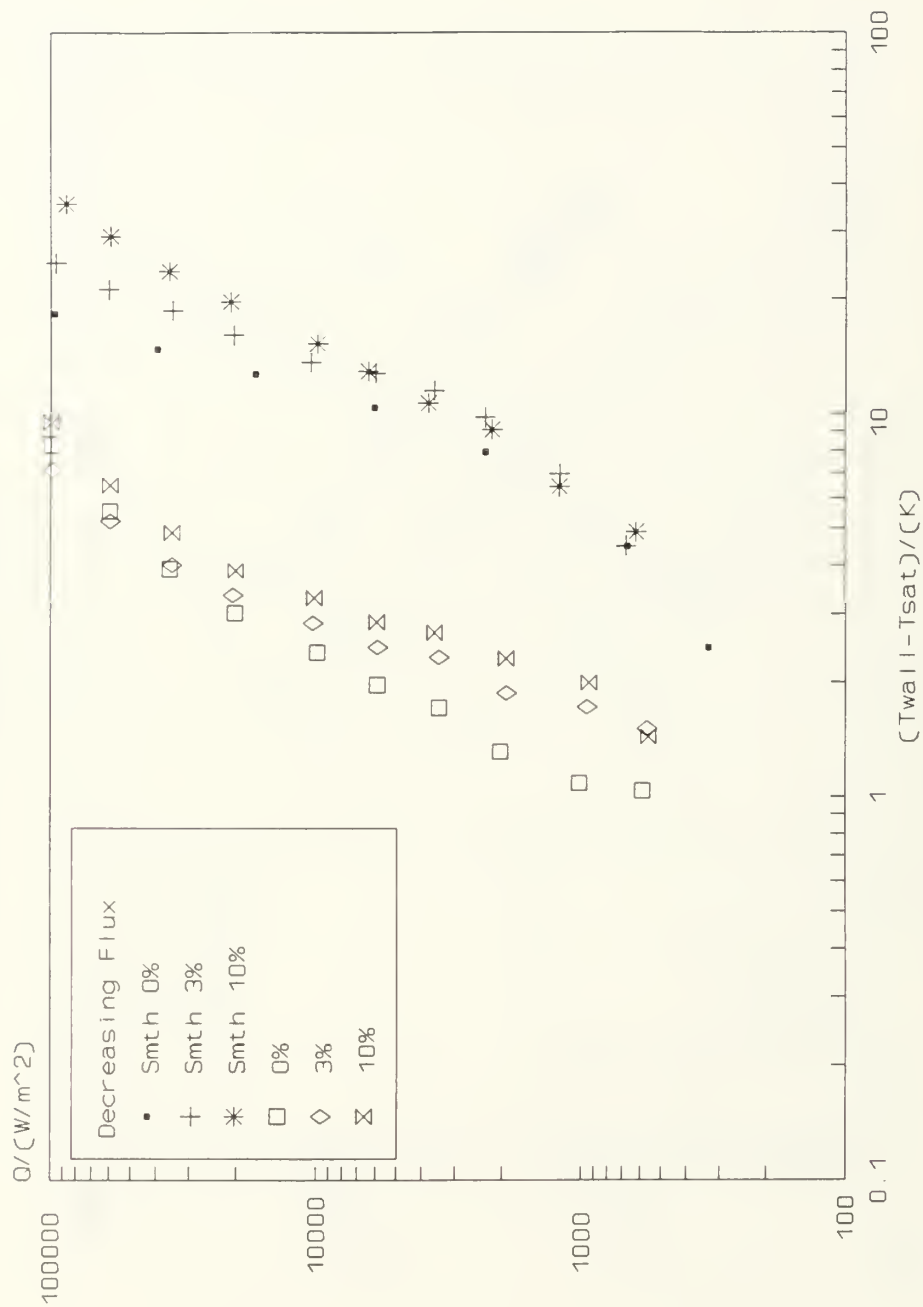
Figure 6.34 Performance Comparison For
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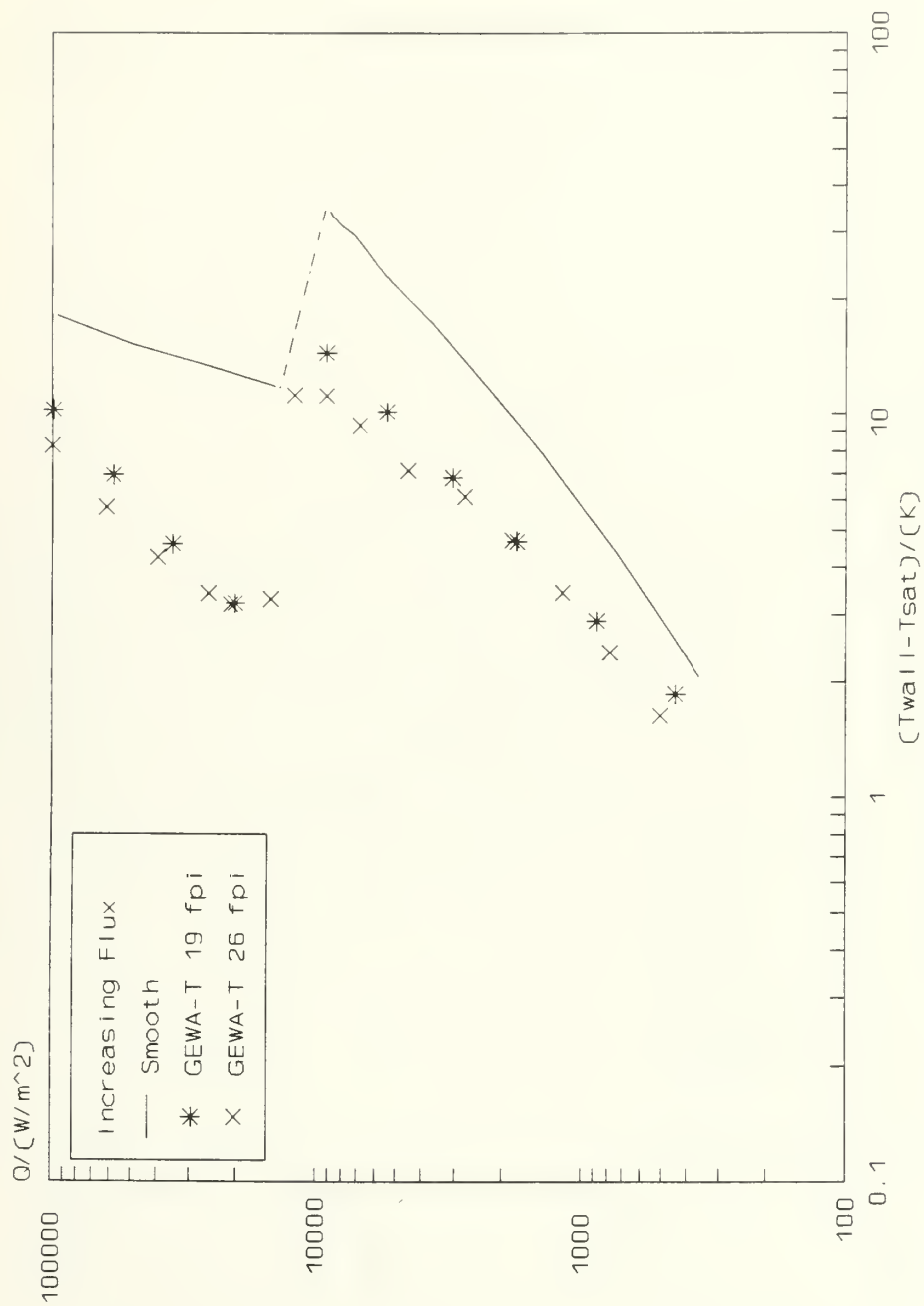
Figure 6.35 Performance Comparison For
Boiling Pure R-114 From
GEWA-T 19/26 fpi Tubes

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Figure 6.36 Performance Comparison For
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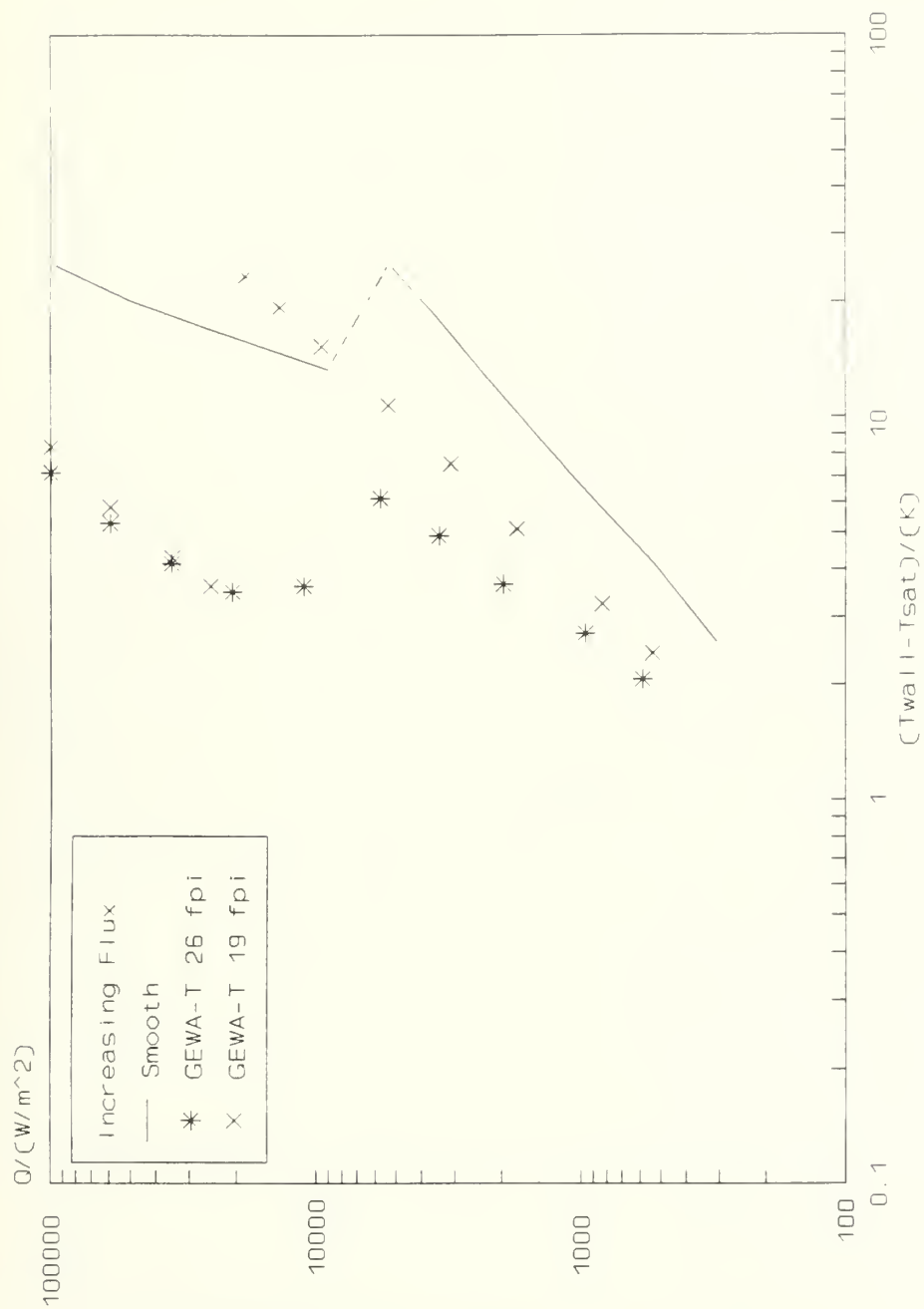
Figure 6.37 Performance Comparison For
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GEWA-T 19/26 fpi Tubes

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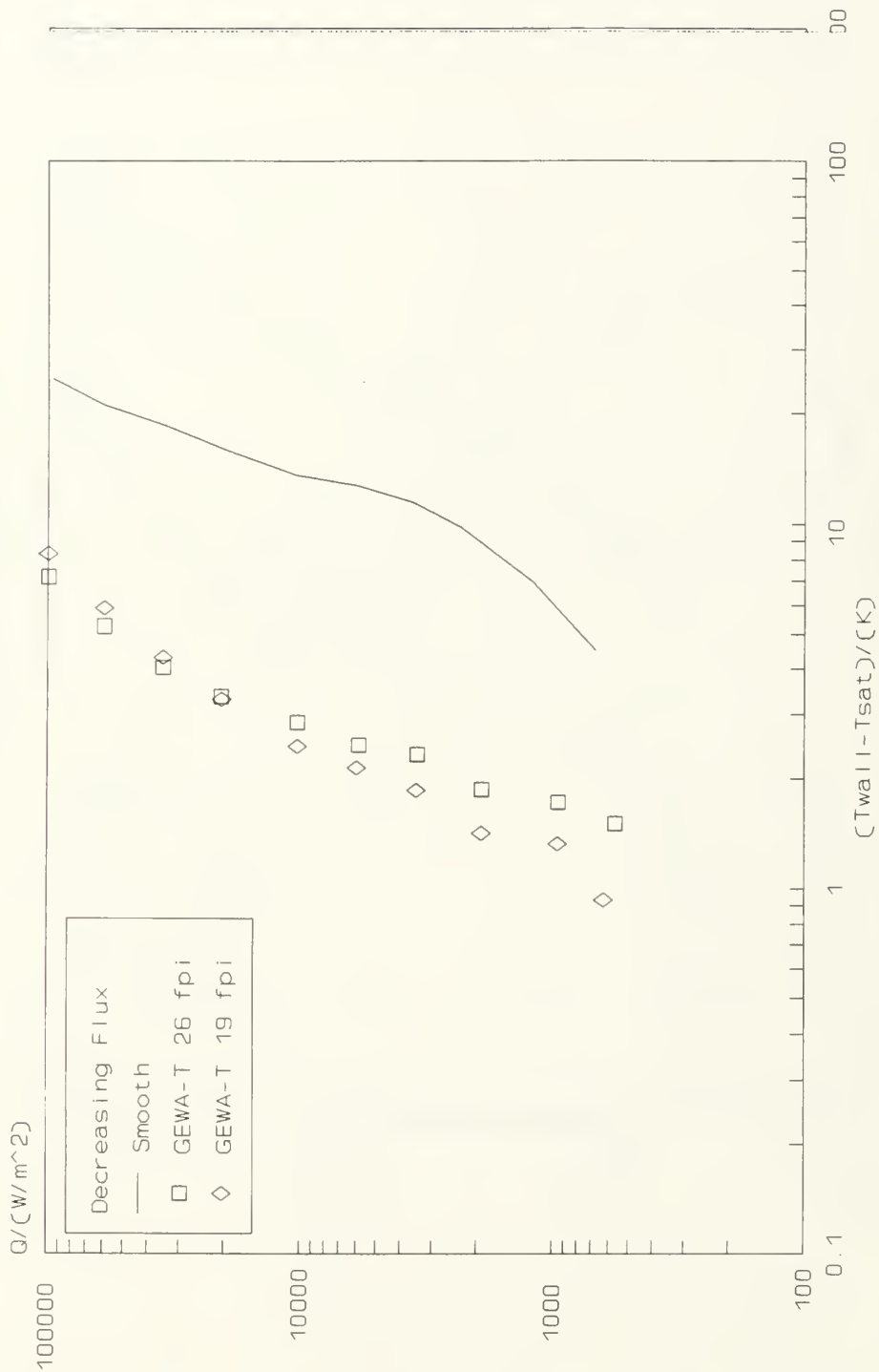
Figure 6.38 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-T 19/26 fpi Tubes

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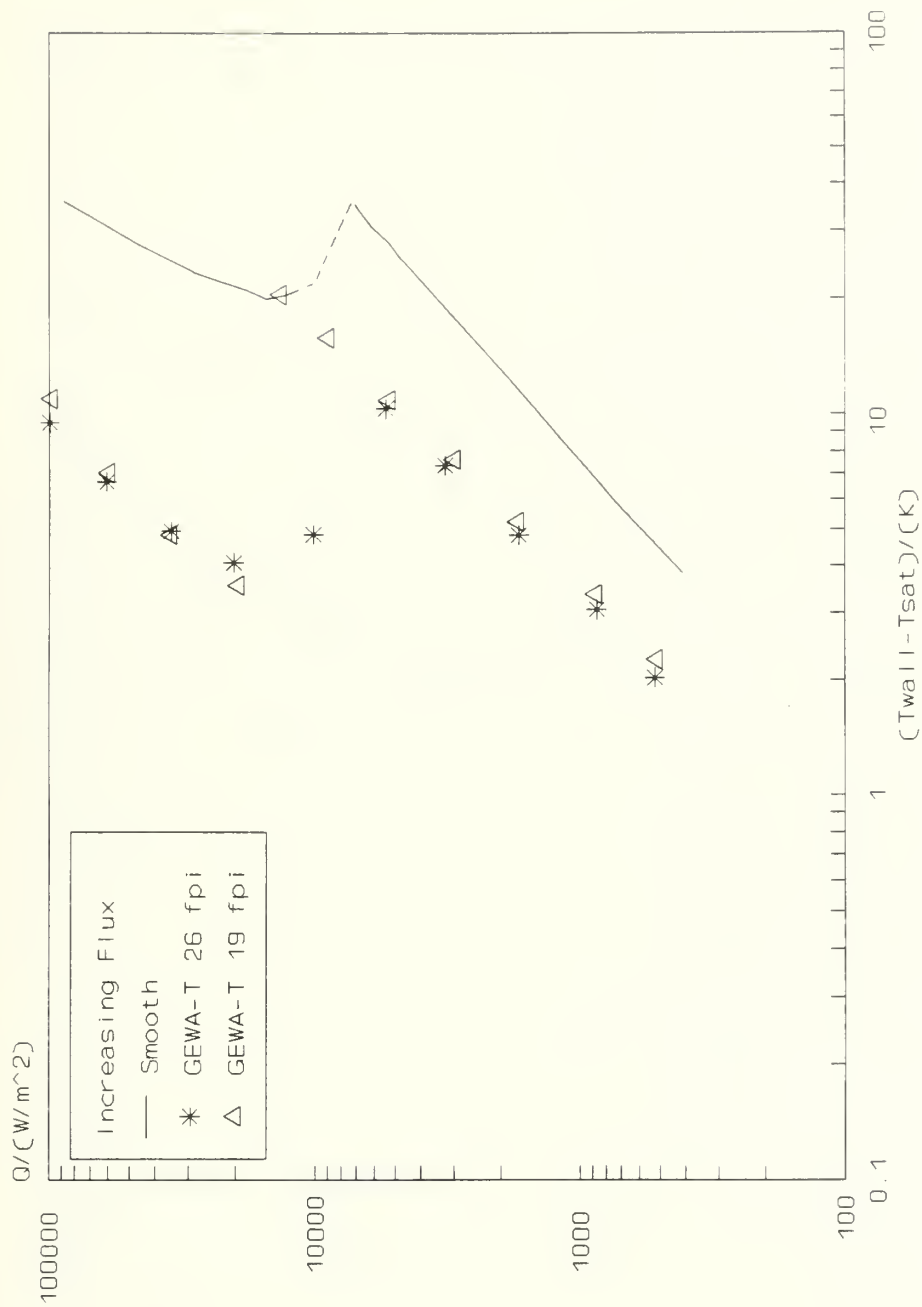
Figure 6.39 Performance Comparison For
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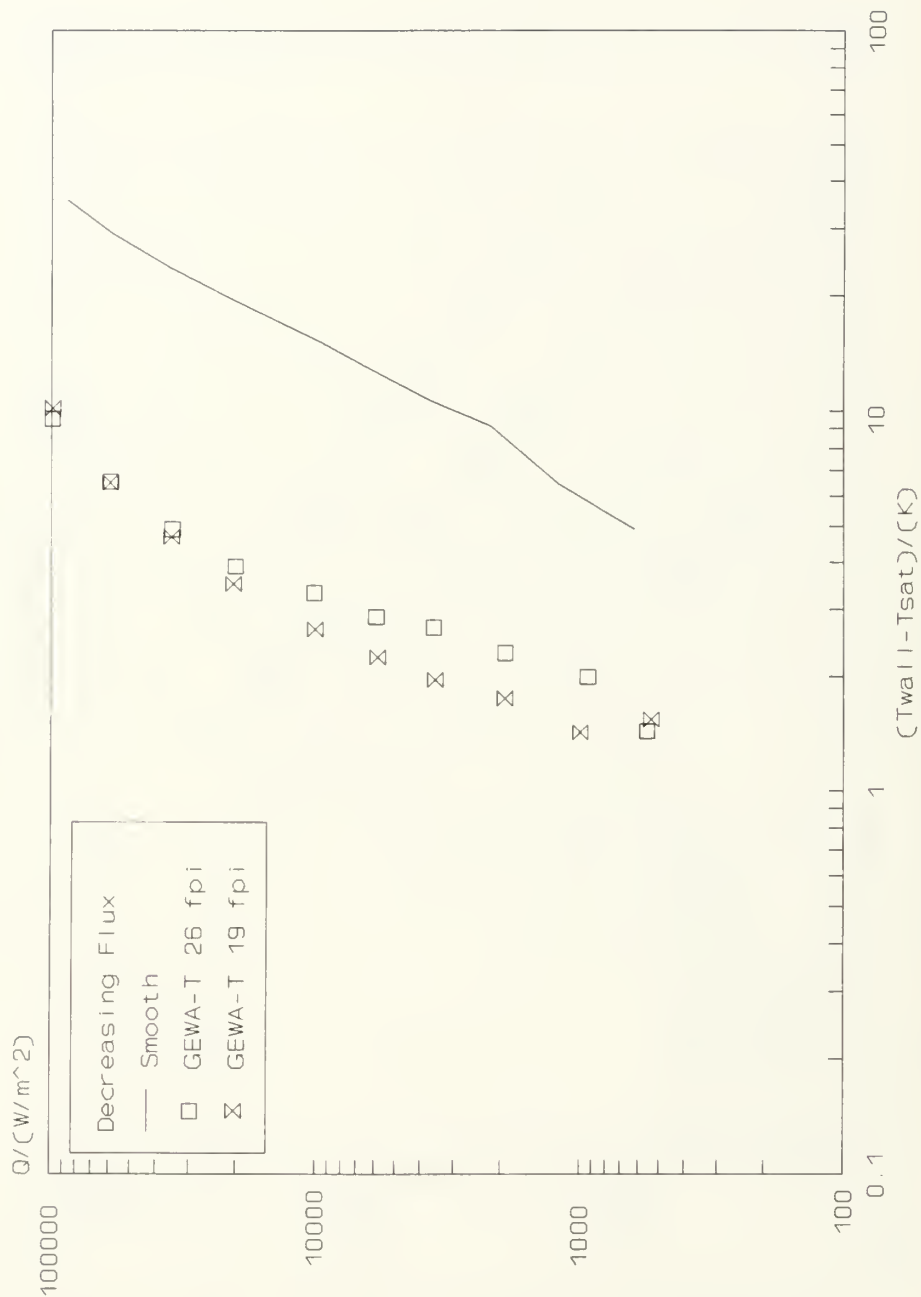
Figure 6.40 Performance Comparison For
Boiling R-114/10% Oil Mixture From
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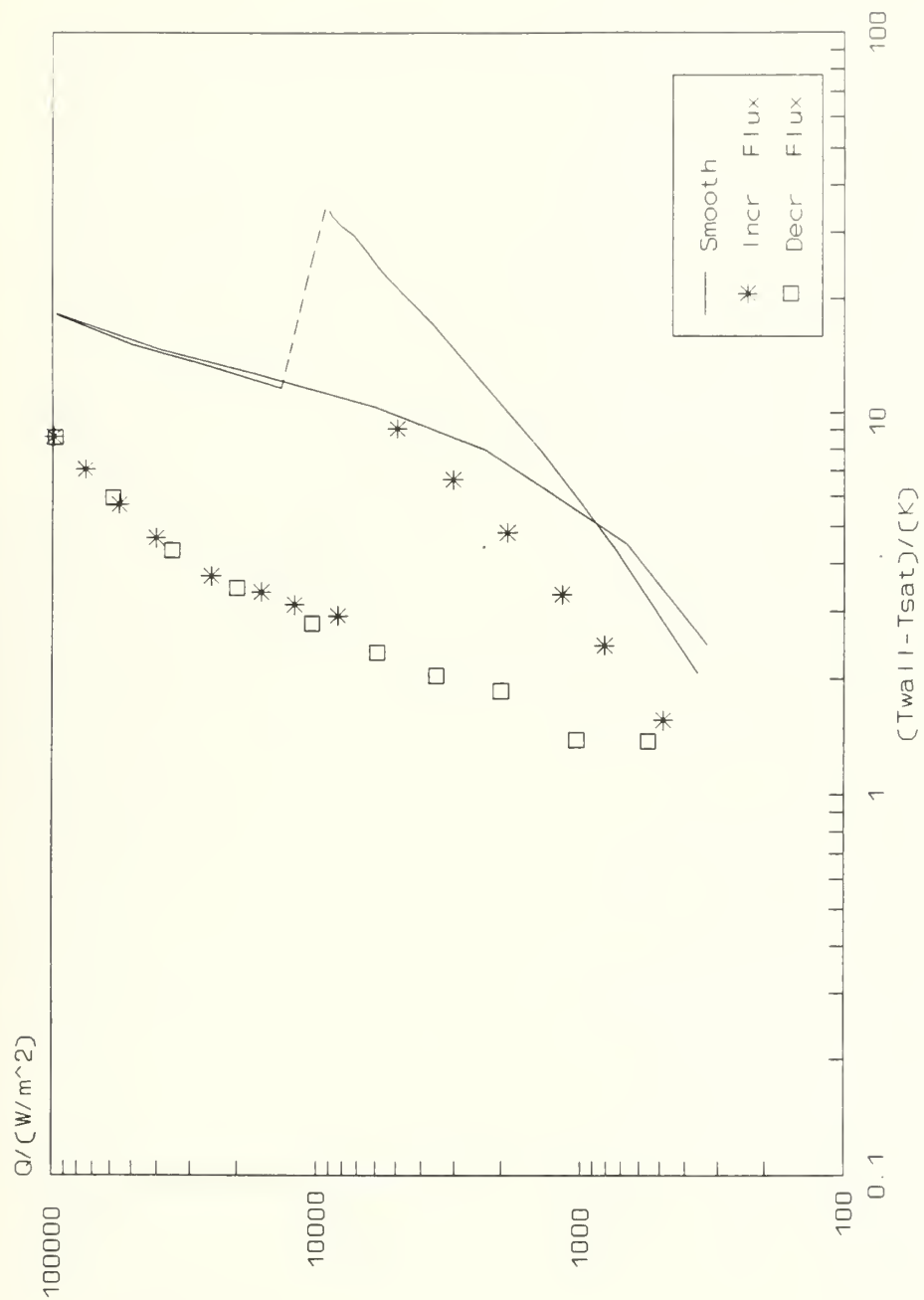
Figure 6.41 Performance Comparison For Boiling Pure R-114 From GEWA-YX 26 fpi Tube

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Figure 6.42 Performance Comparison For
Boiling R-114/3% Oil Mixture From
GEWA-YX 26 fpi Tube
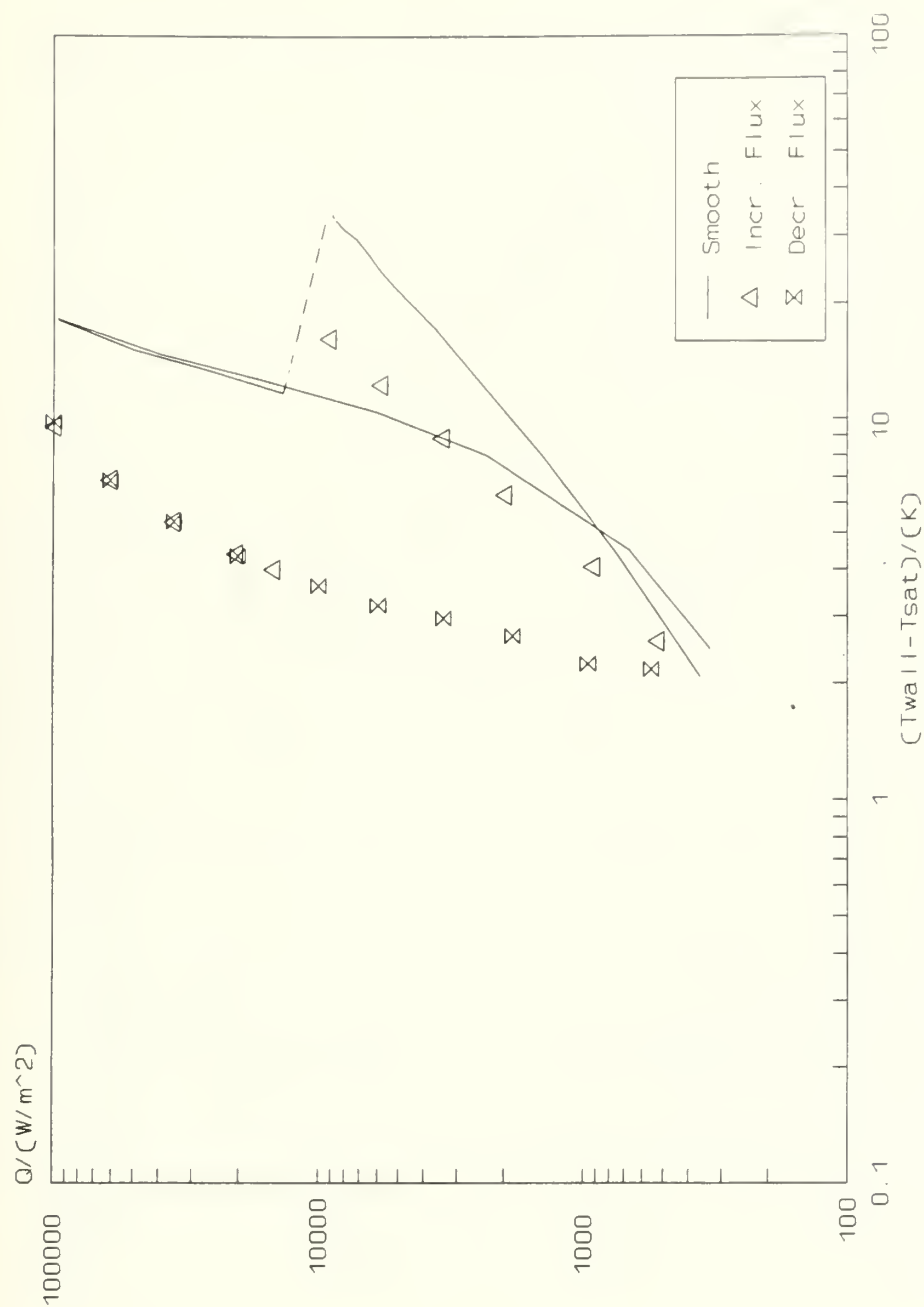
Figure 6.43 Performance Comparison For
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GEWA-YX 26 fpi Tube

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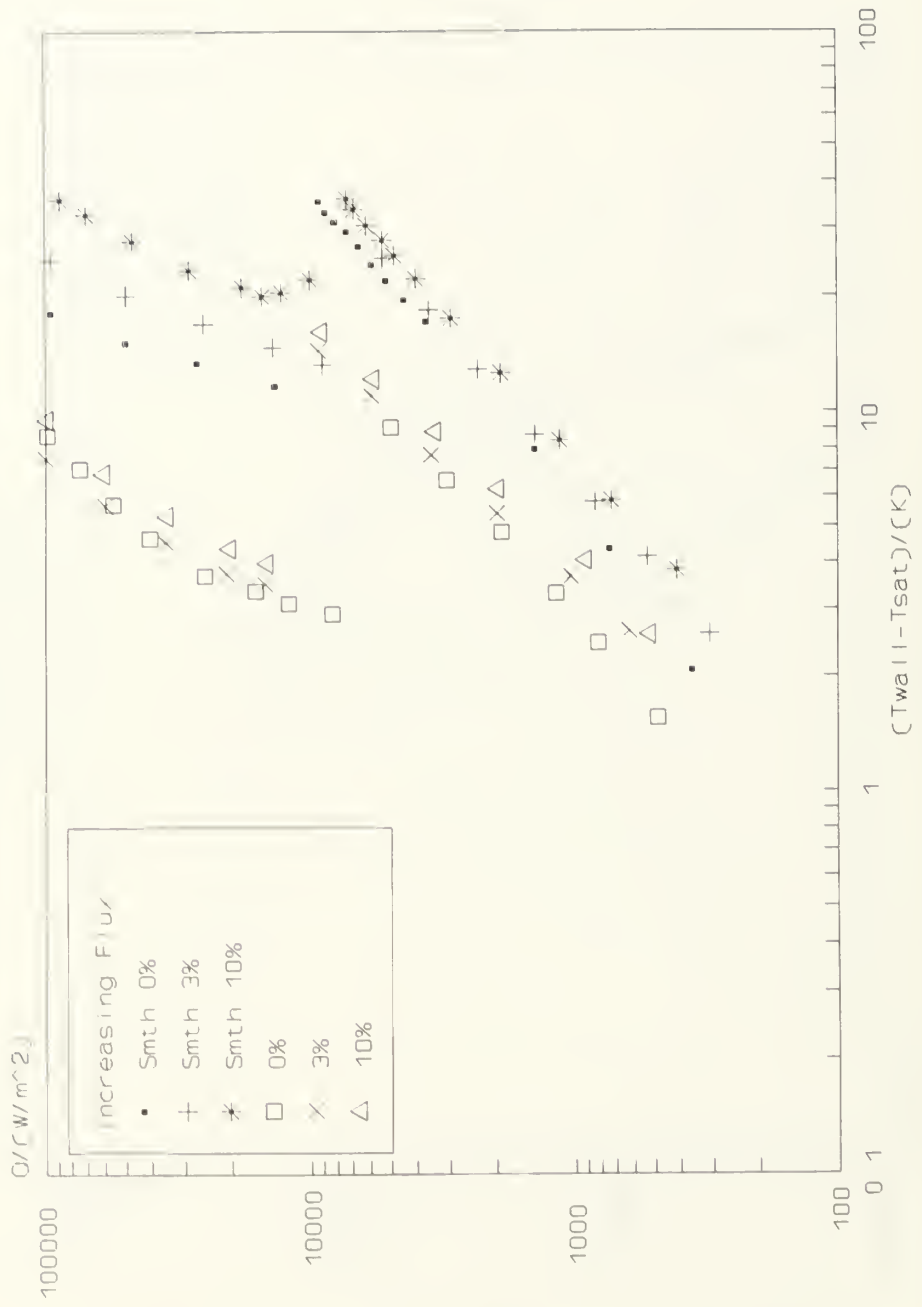
Figure 6.44 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
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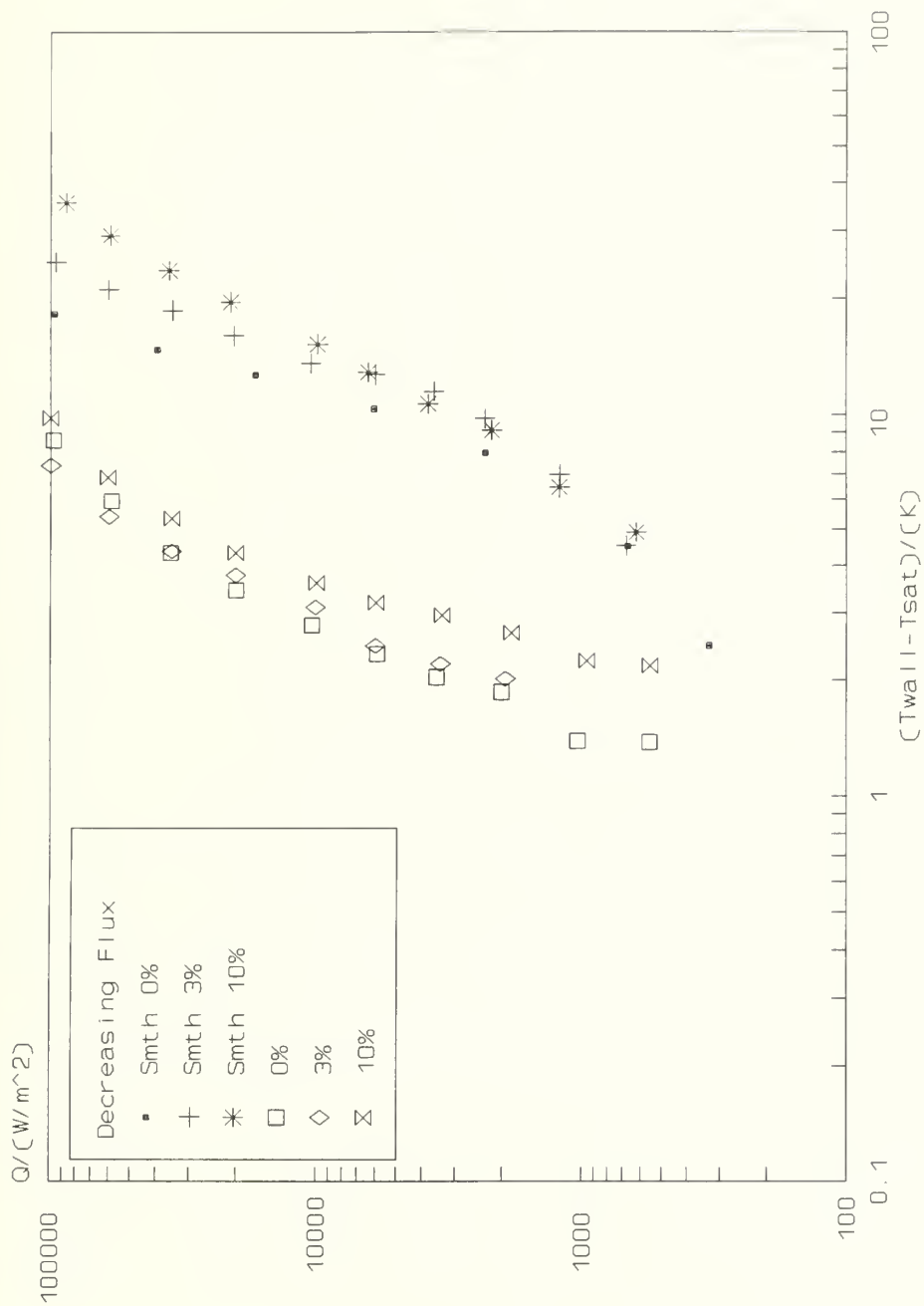
Figure 6.45 Performance Comparison For
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From GEWA-YX 26 fpi Tube

101
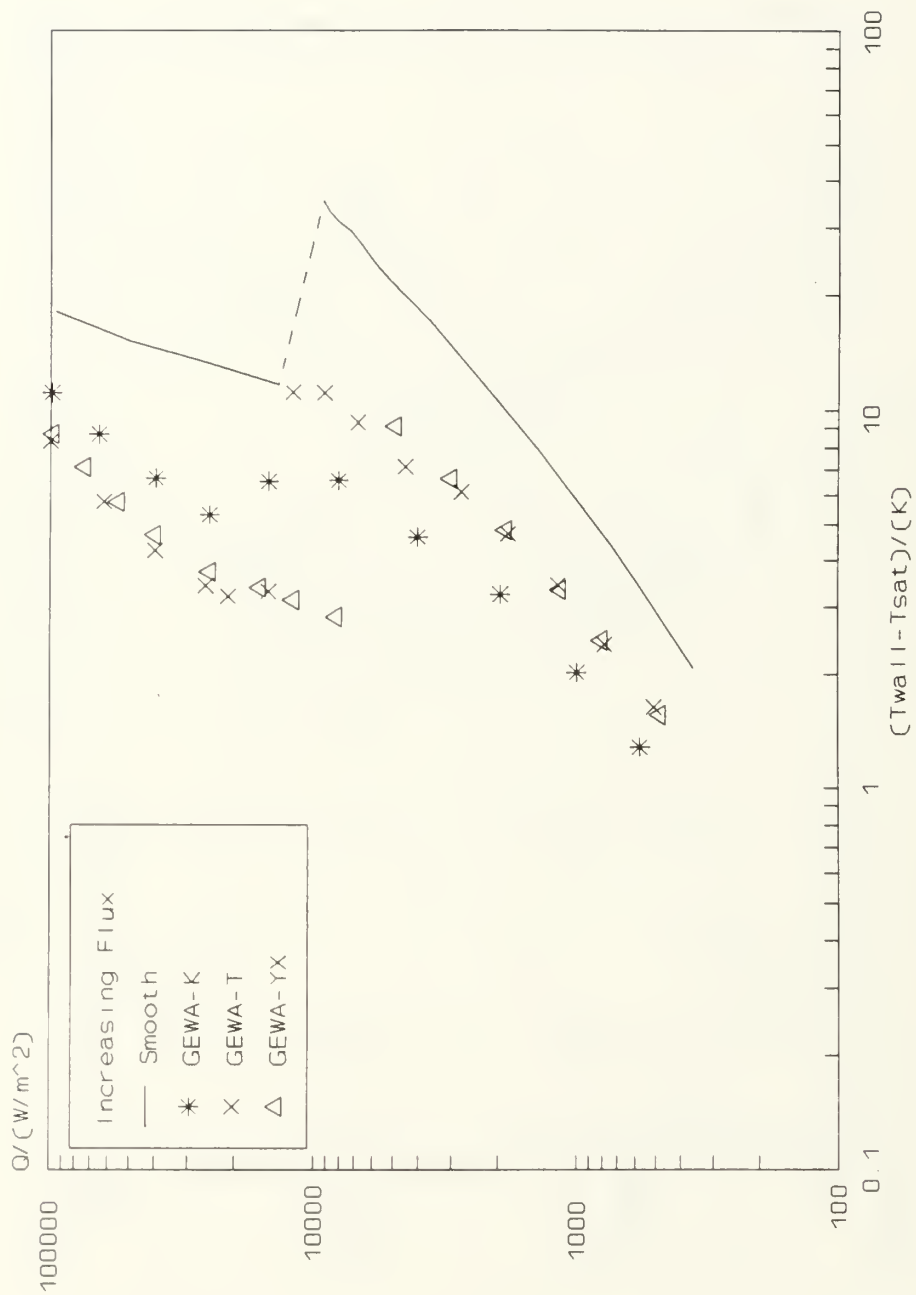
Figure 6.46 Performance Comparison For
Pure R-114 Boiling From
GEWA-K\T\YX 26 fpi Tubes
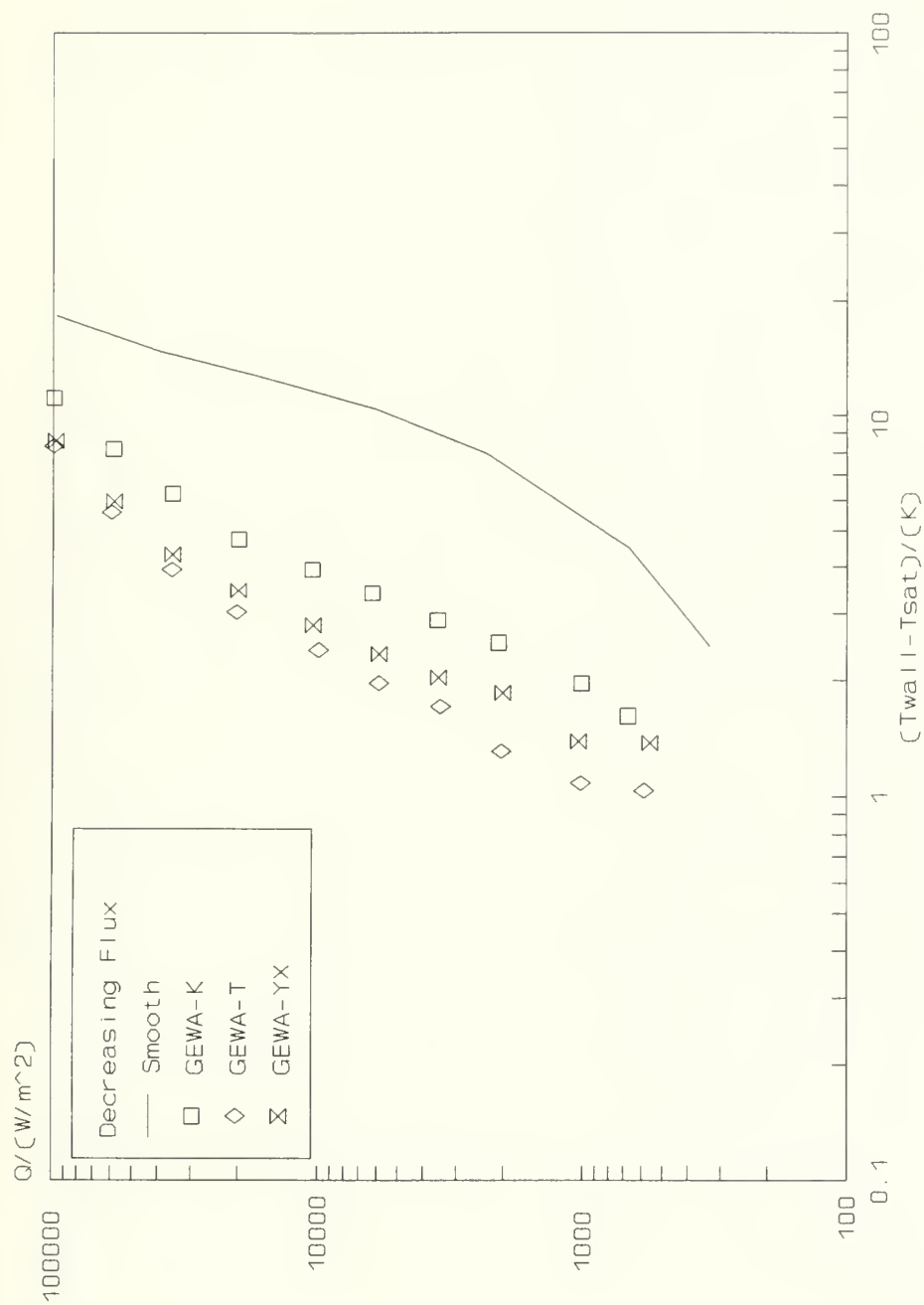
Figure 6.47 Performance Comparison For
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GEWA-K/T/YX 26 fpi Tubes

103
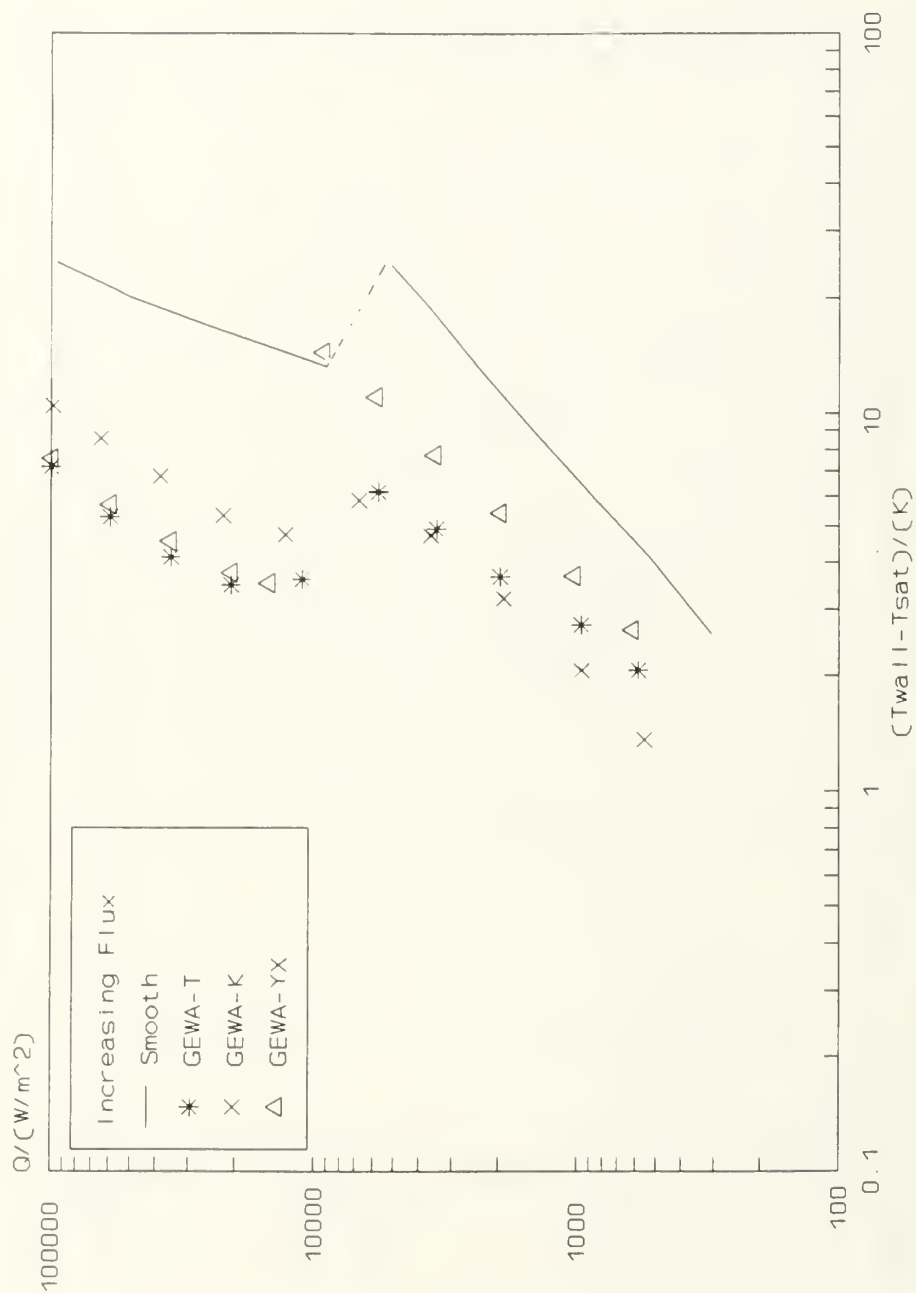
Figure 6.48 Performance Comparison For
Boiling R-114/3% Oil Mixture From
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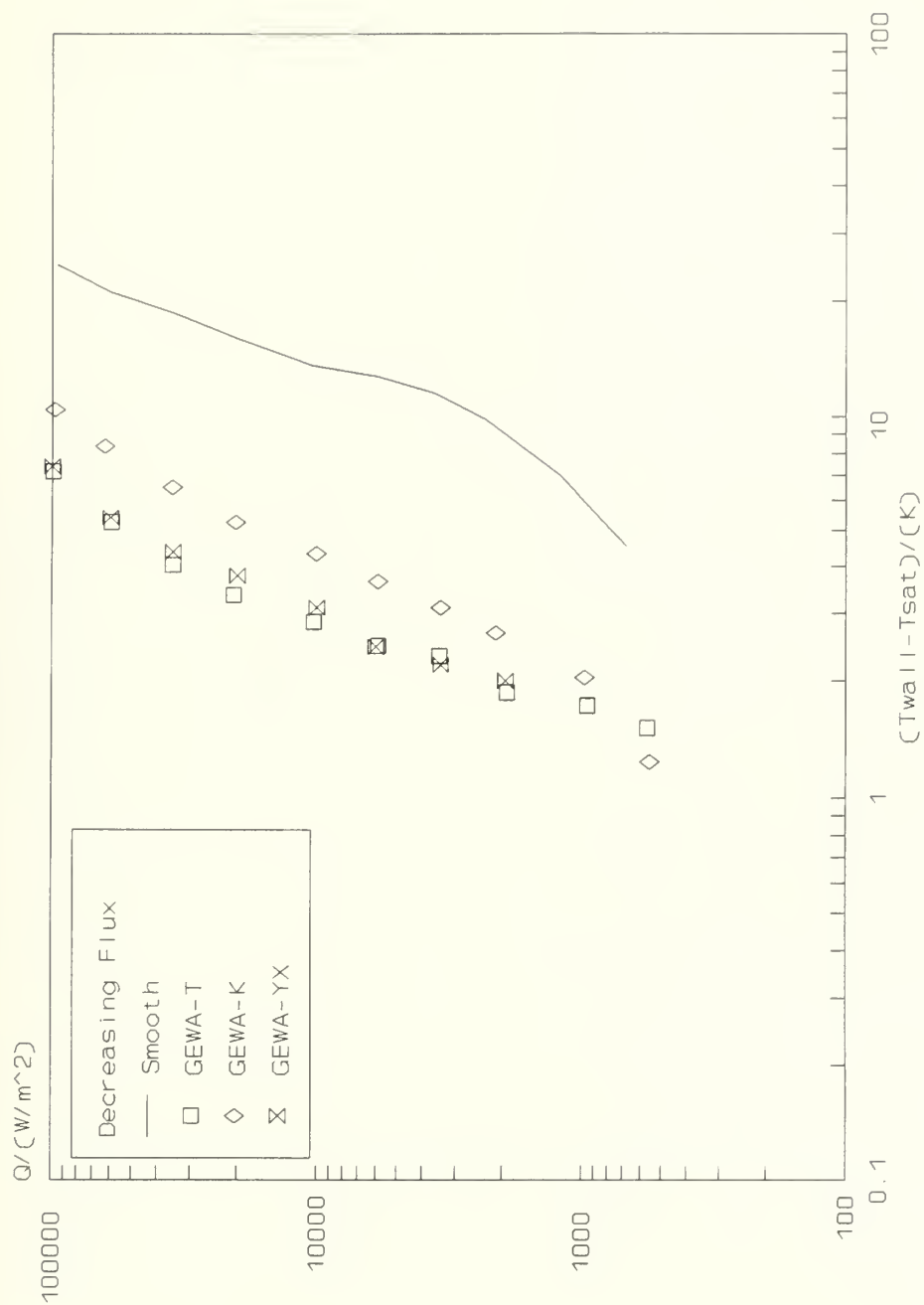
Figure 6.49 Performance Comparison For Boiling R-114/3% Oil Mixture From GEWA-K/T/YX 26 fpi Tubes
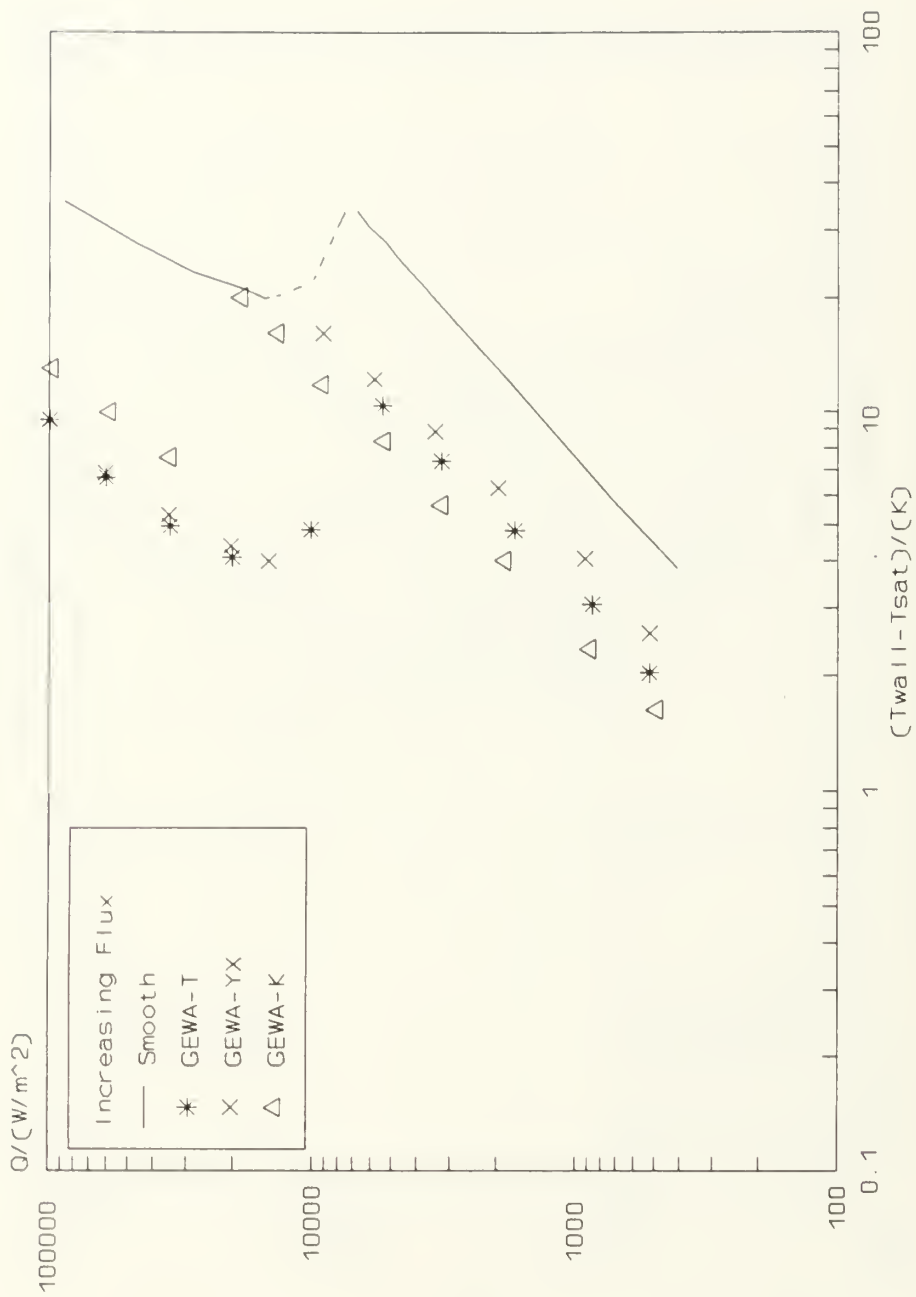
Figure 6.50 Performance Comparison For
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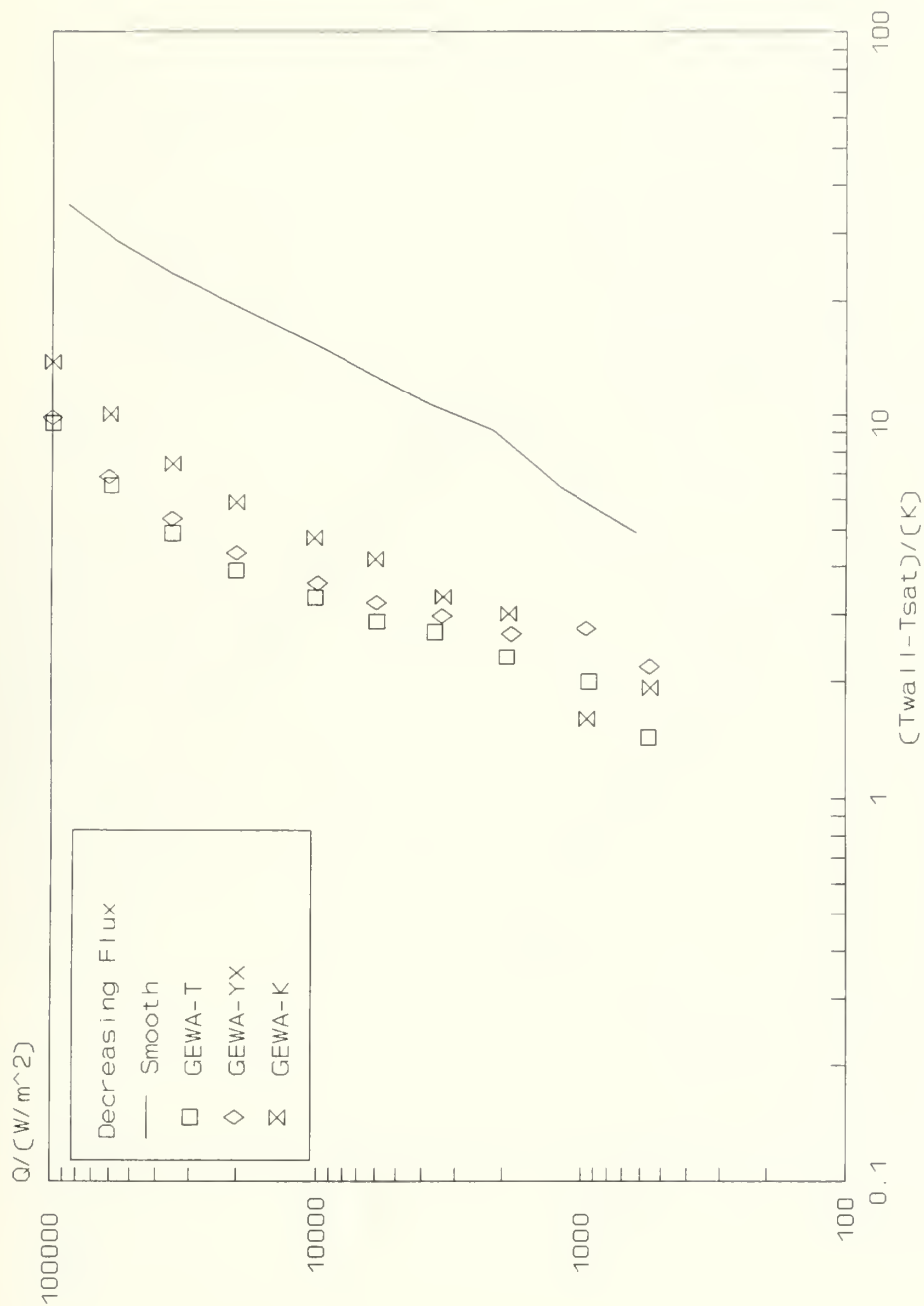
Figure 6.51 Performance Comparison For
Boiling R-114/10% Oil Mixture From
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Figure 6.52 Performance Comparison for
Pure R-114 Boiling from
High Flux Tube

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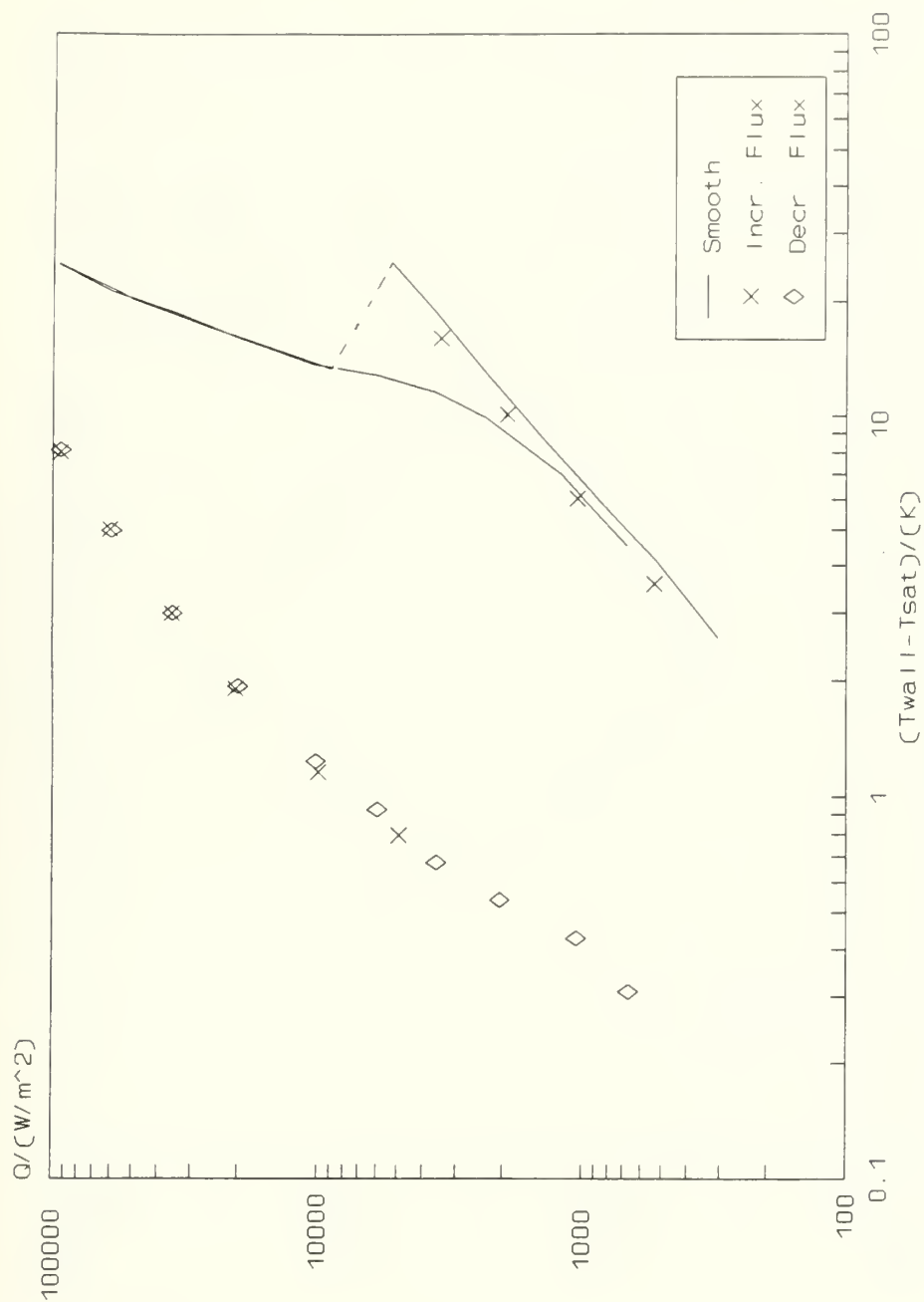
Figure 6.53 Performance Comparison For
Boiling R-114/3% Oil Mixture From
High Flux Tube

Figure 6.54 Performance Comparison For
Boiling R-114/10% Oil Mixture From
High Flux Tube

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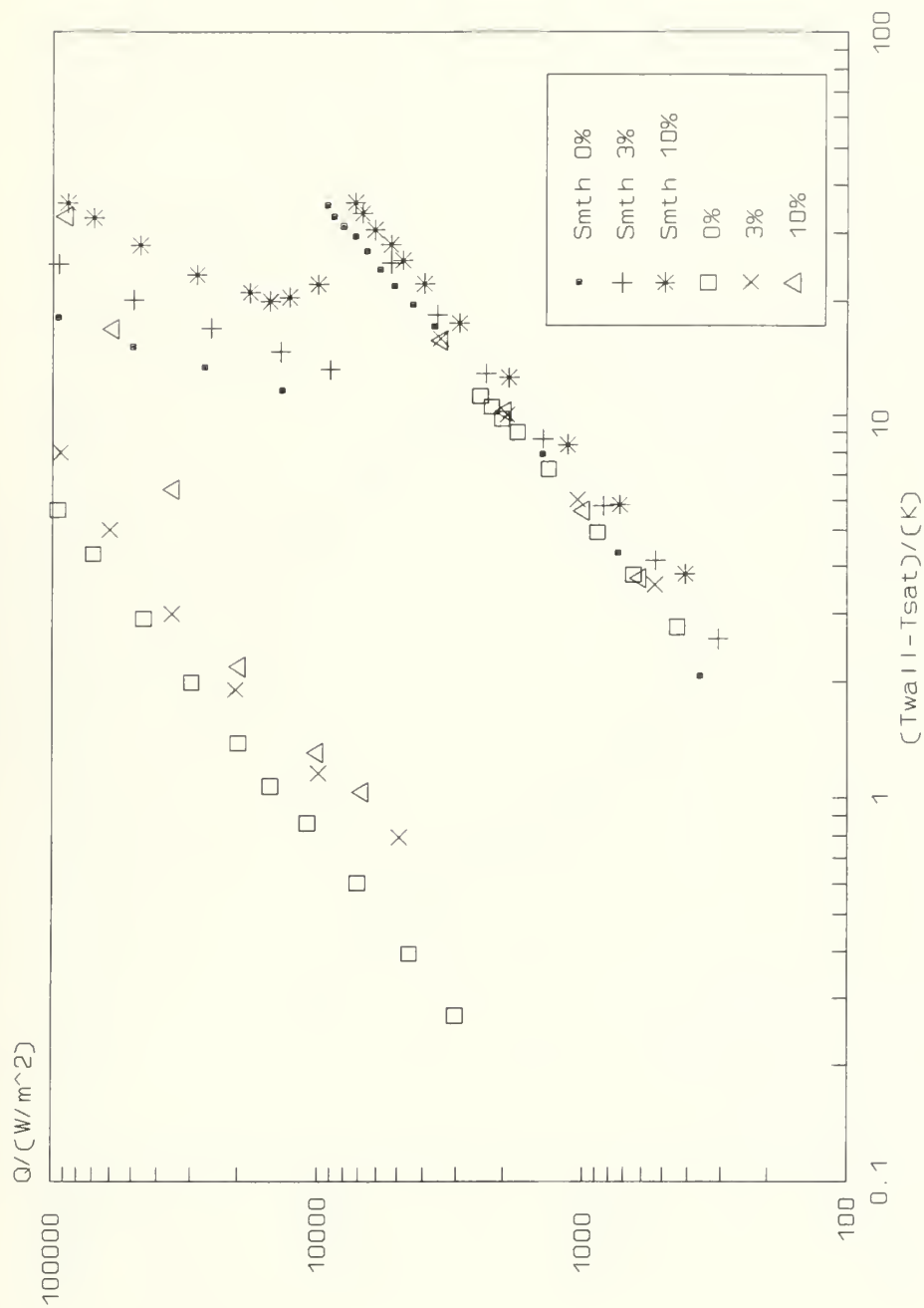
Figure 6.55 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From High Flux Tube

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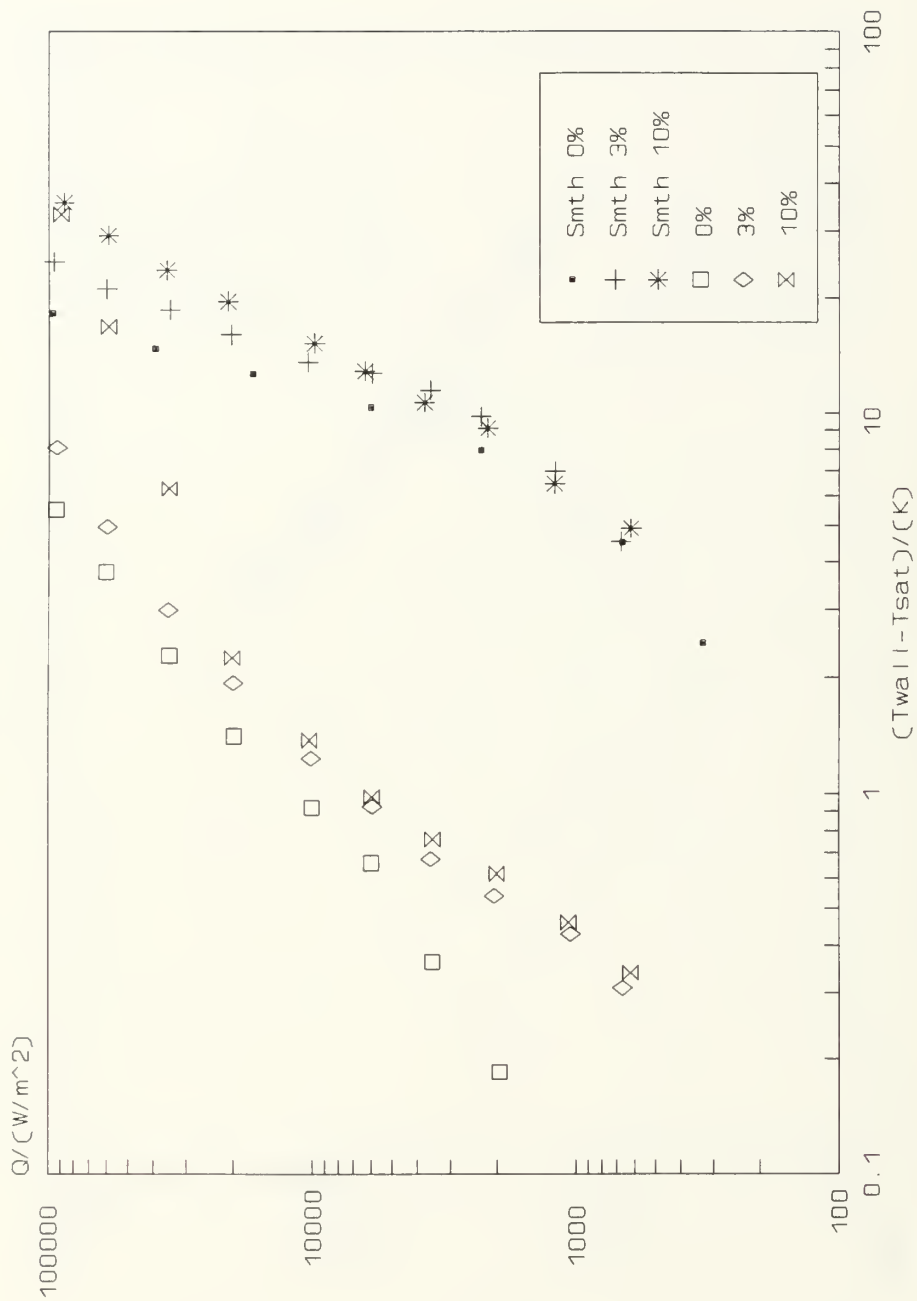
Figure 6.56 Performance Comparison For
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Decreasing Flux From High Flux Tube

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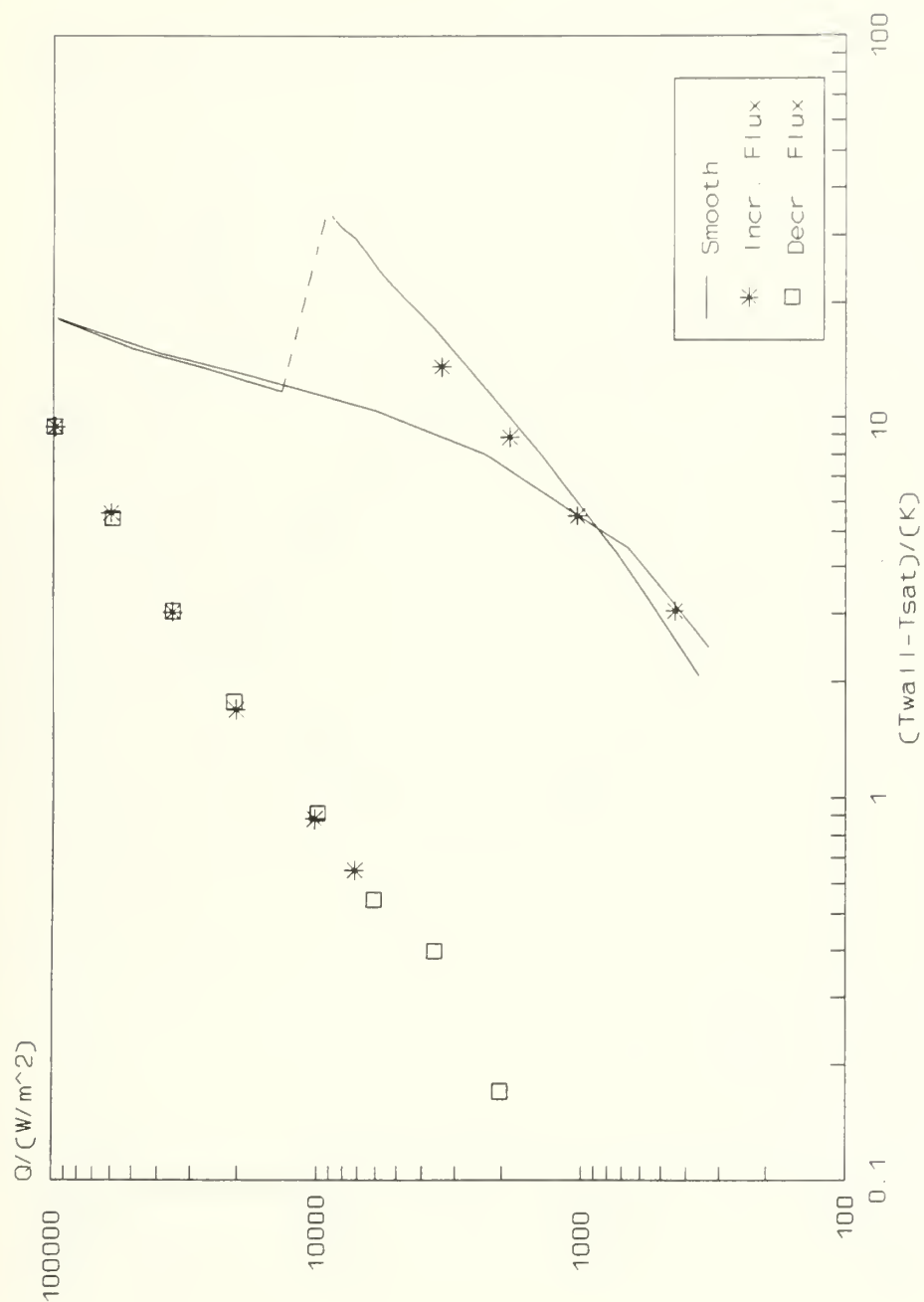
Figure 6.57 Performance Comparison For
Pure R-114 Boiling From
Thermoexcel-E Tube

113

Figure 6.58 Performance Comparison For
Boiling R-114/3% Oil Mixture From
Thermoexcel-E Tube

114
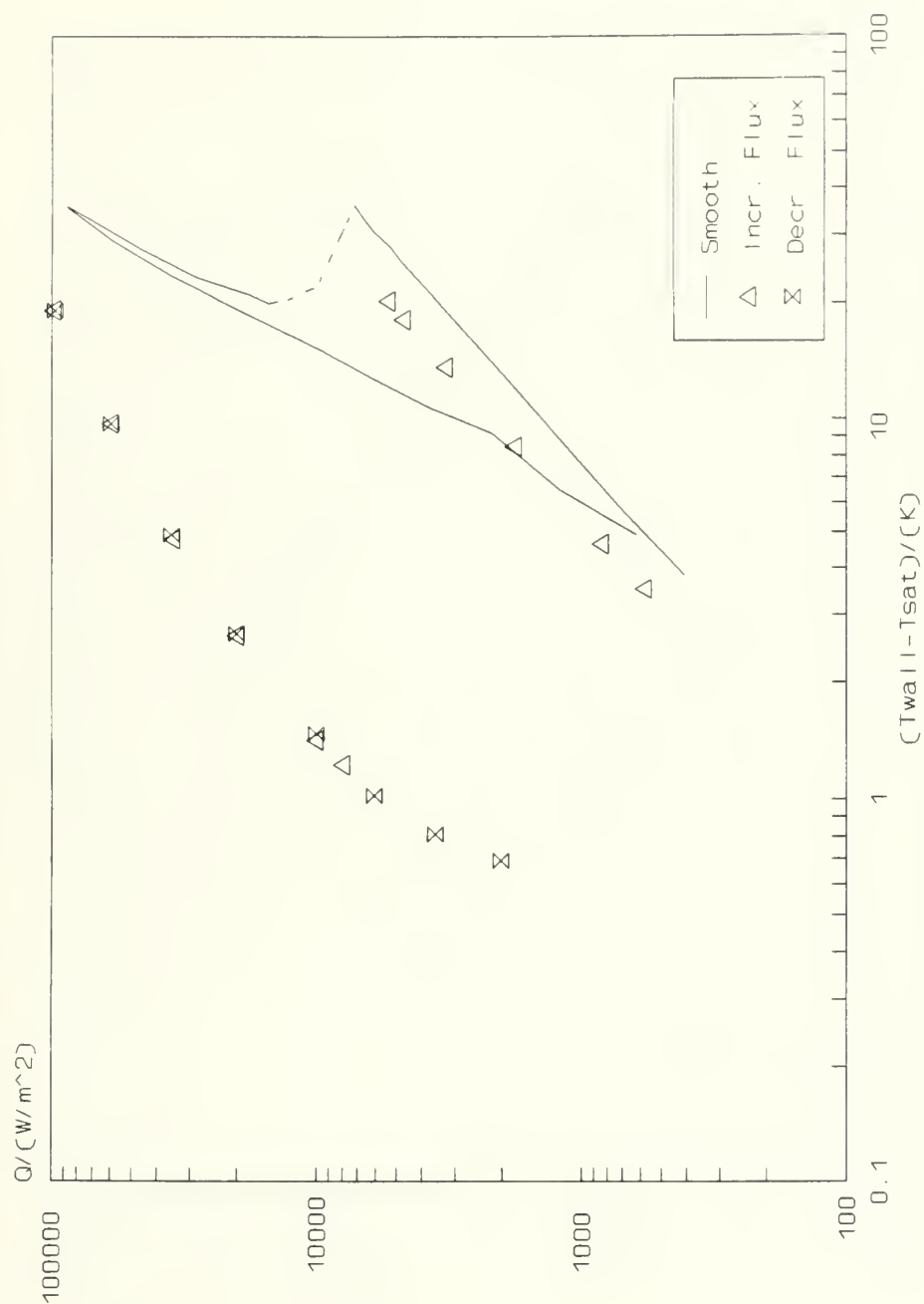
Figure 6.59 Performance Comparison For
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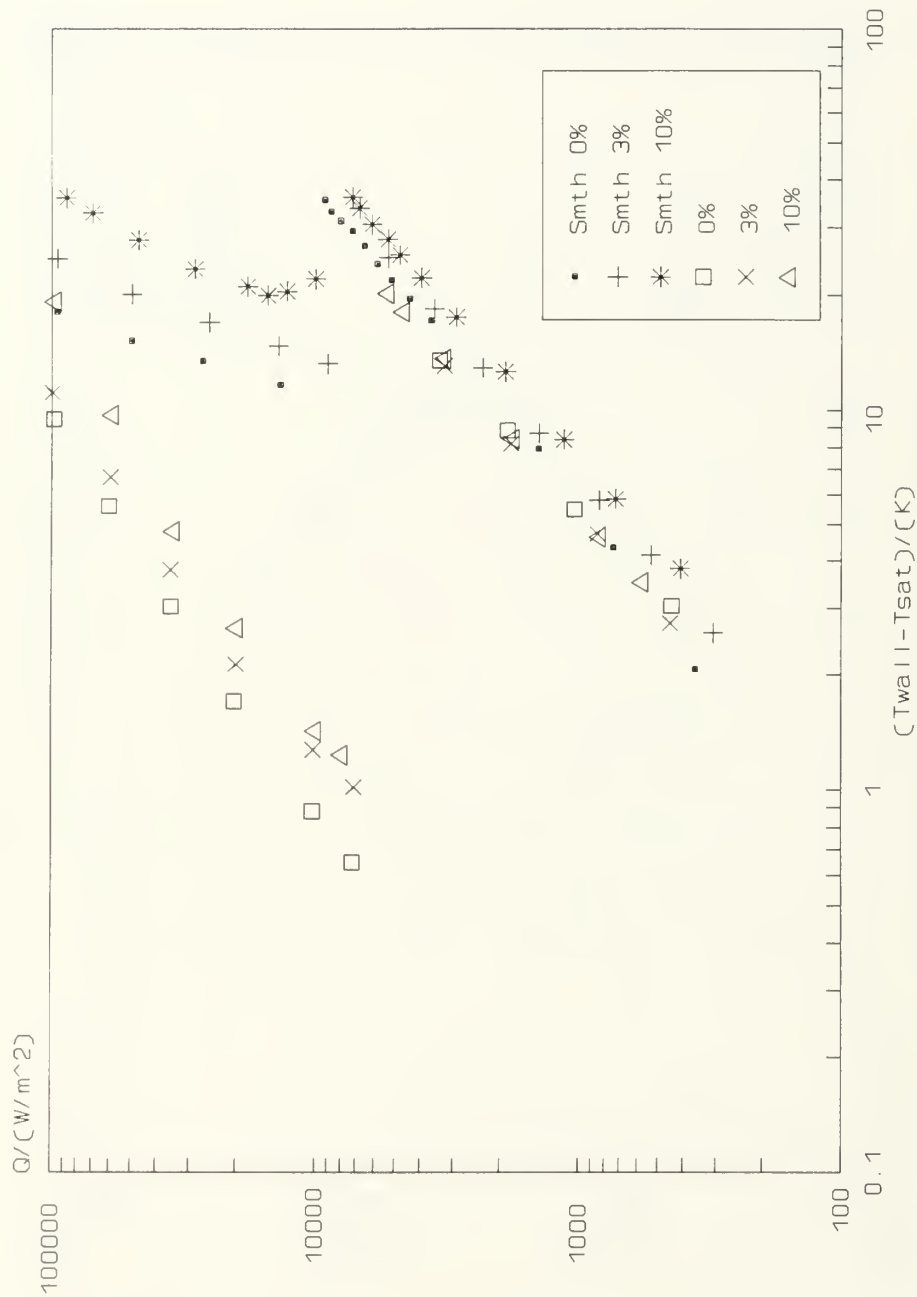
Figure 6.60 Performance Comparison For
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Increasing Flux From Thermoexcel-E Tube
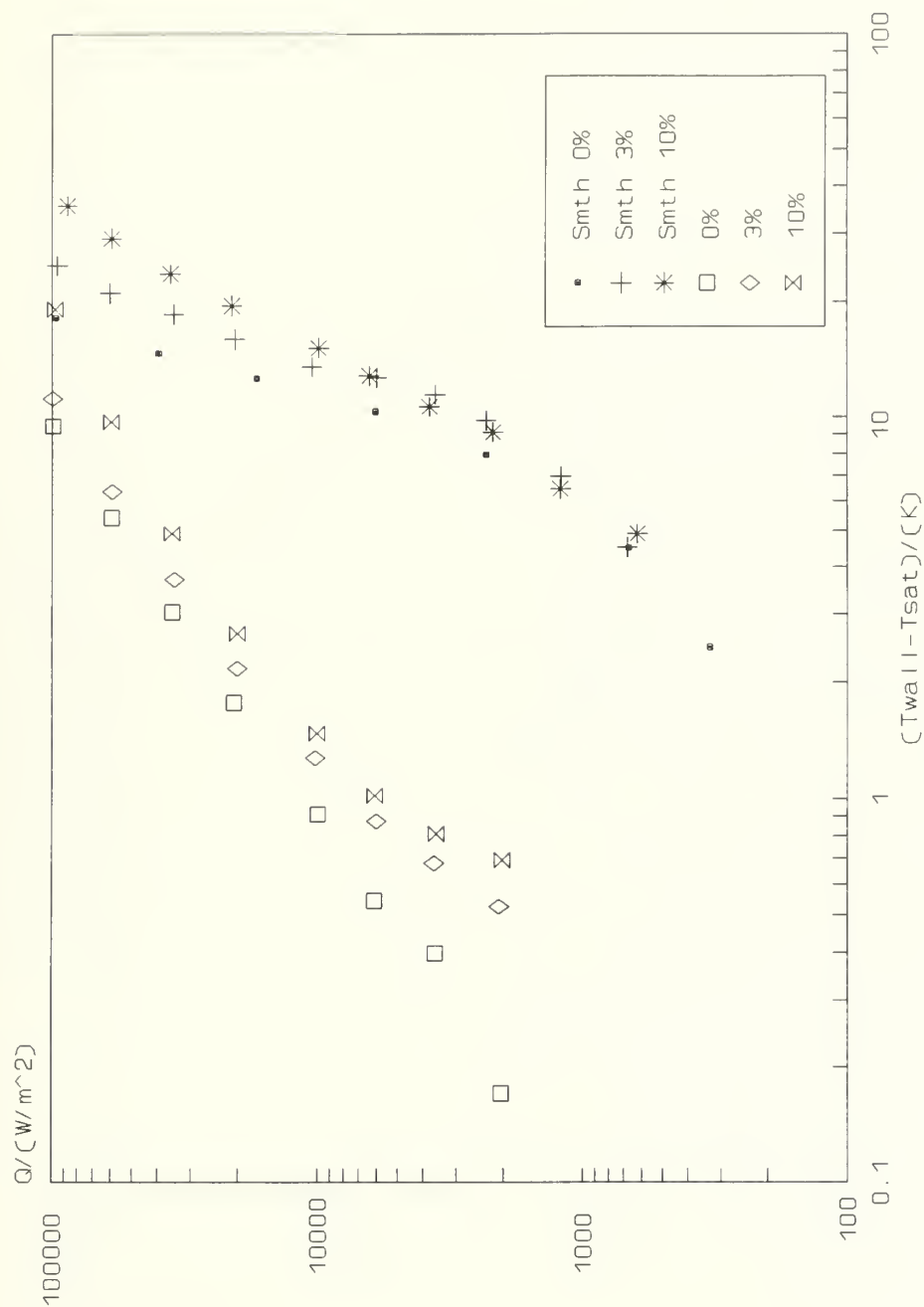
Figure 6.61 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Thermoexcel-E Tube

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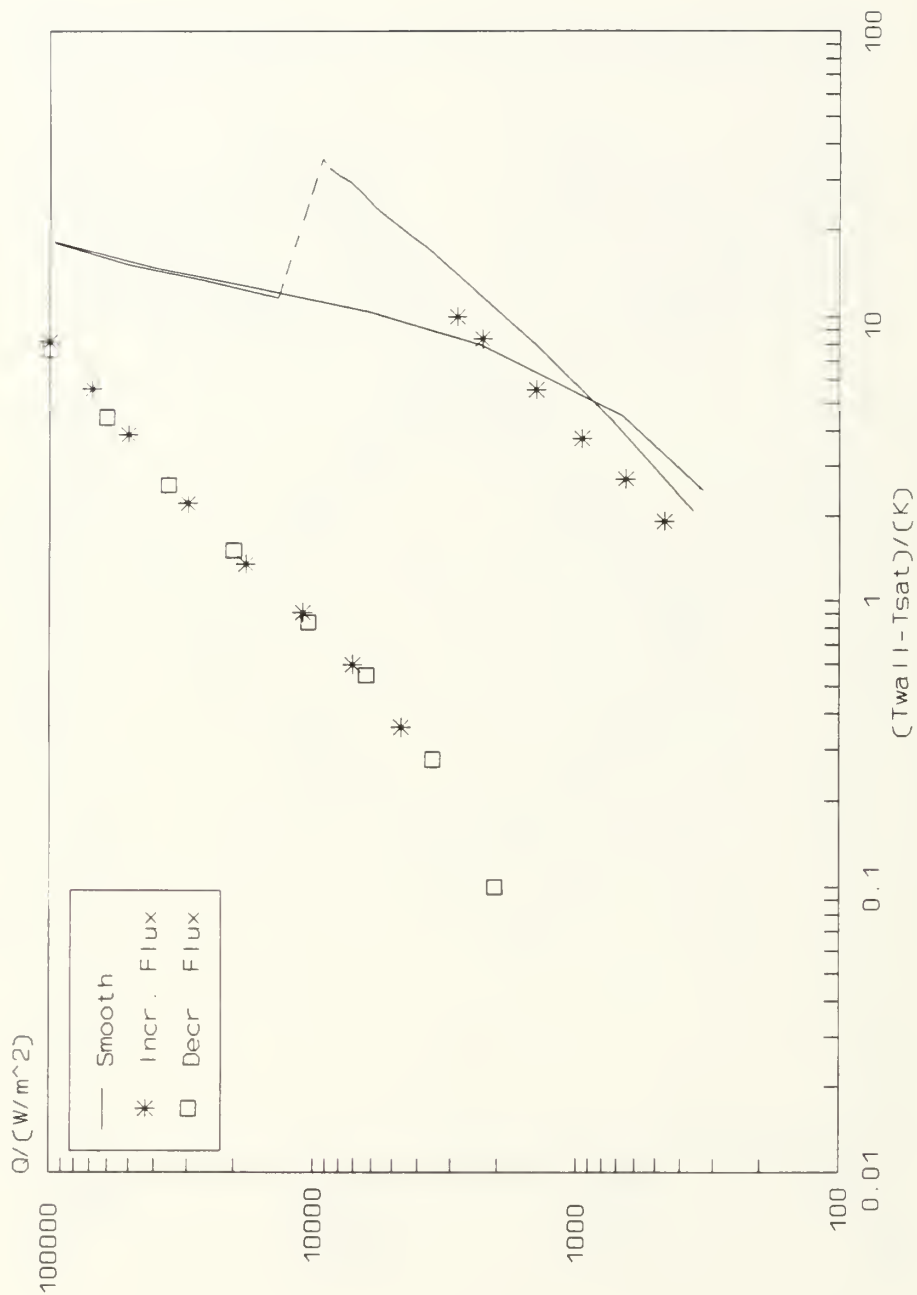
Figure 6.62 Performance Comparison For
Pure R-114 Boiling From
Thermoexcel-HE Tube
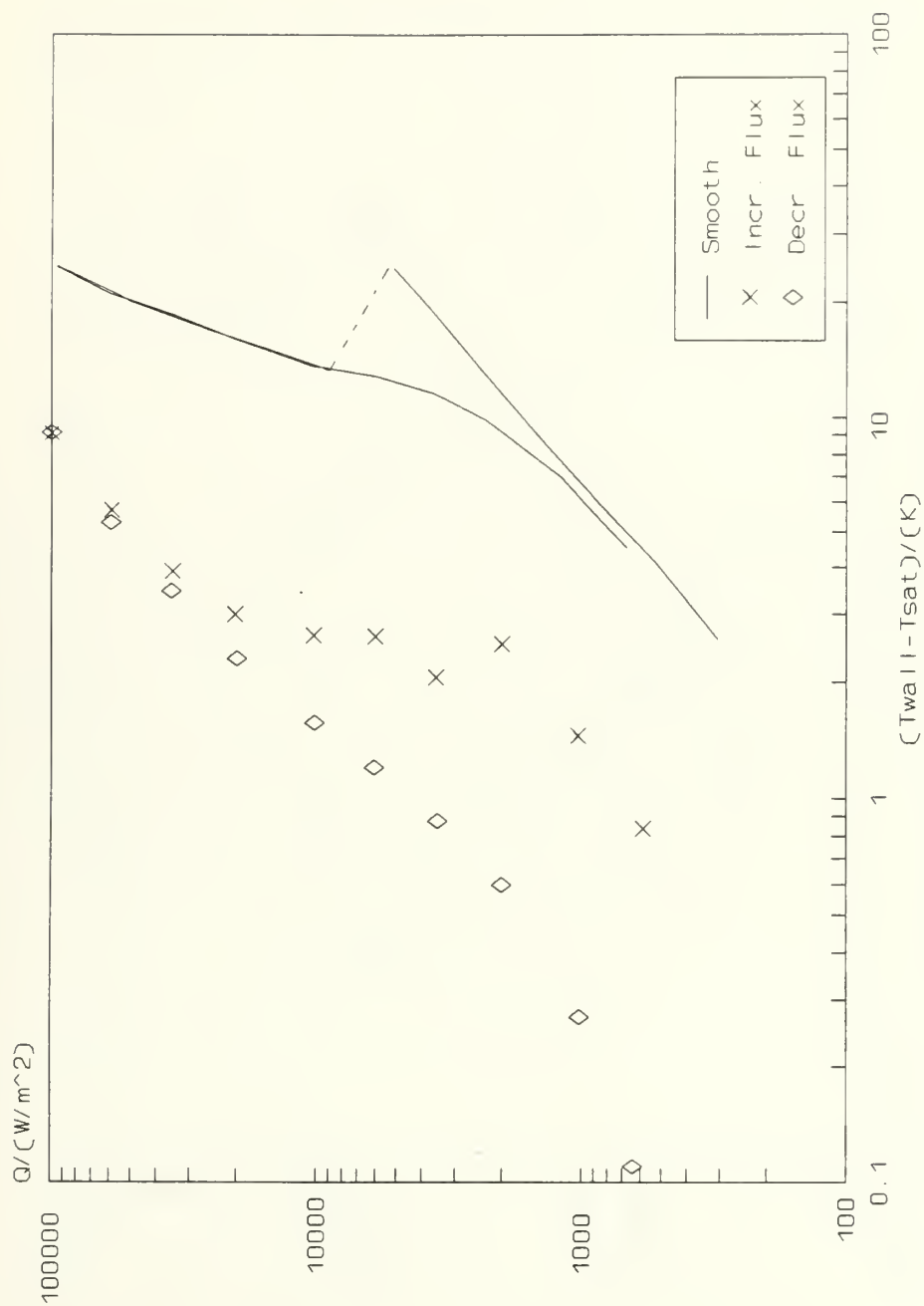
Figure 6.63 Performance Comparison For
Boiling R-114/3% Oil Mixture From
Thermoexcel-HE Tube

Figure 6.64 Performance Comparison For
Boiling R-114/10% Oil Mixture From
Thermoexcel-HE Tube
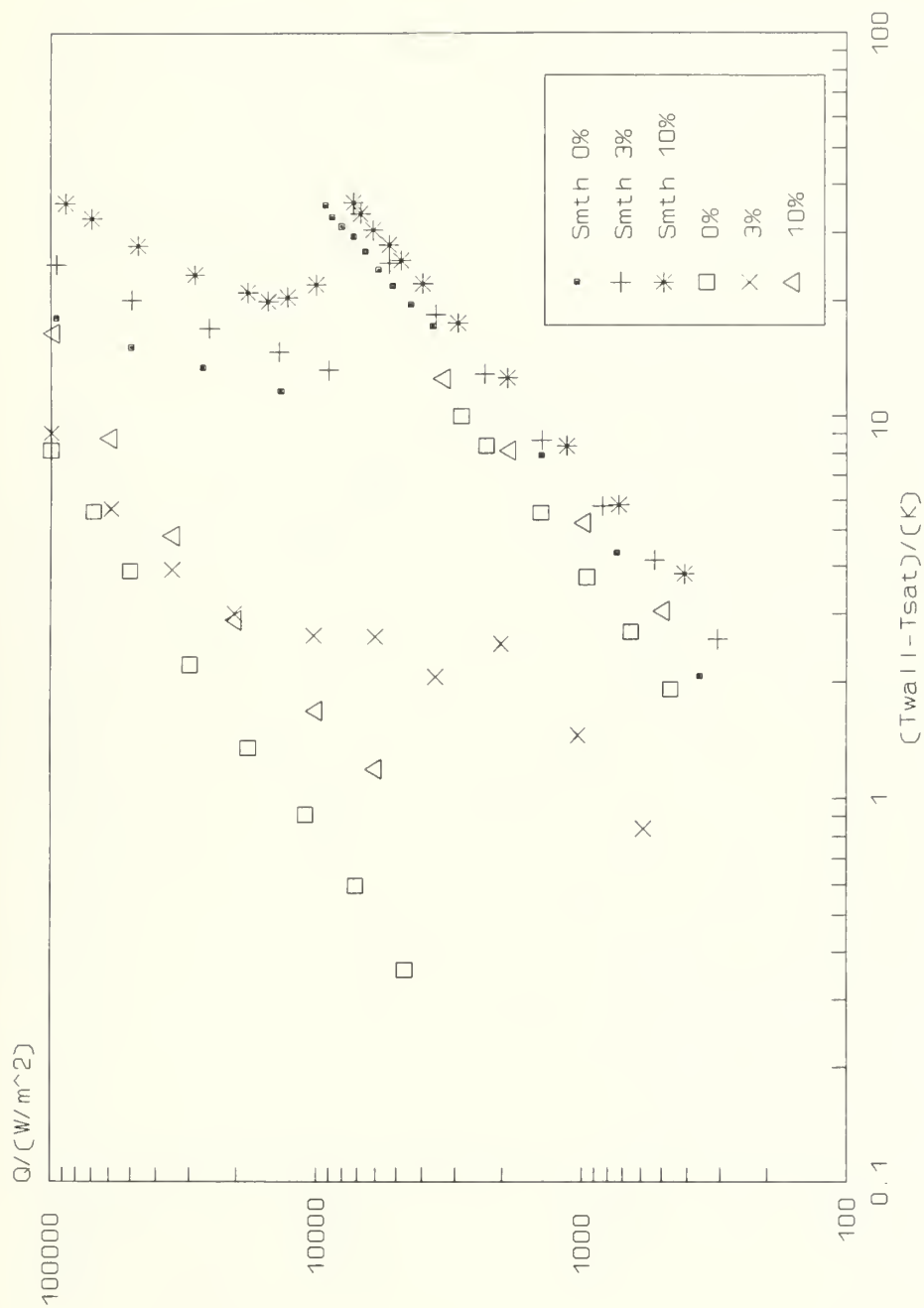
Figure 6.65 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Thermoexcel-HE Tube
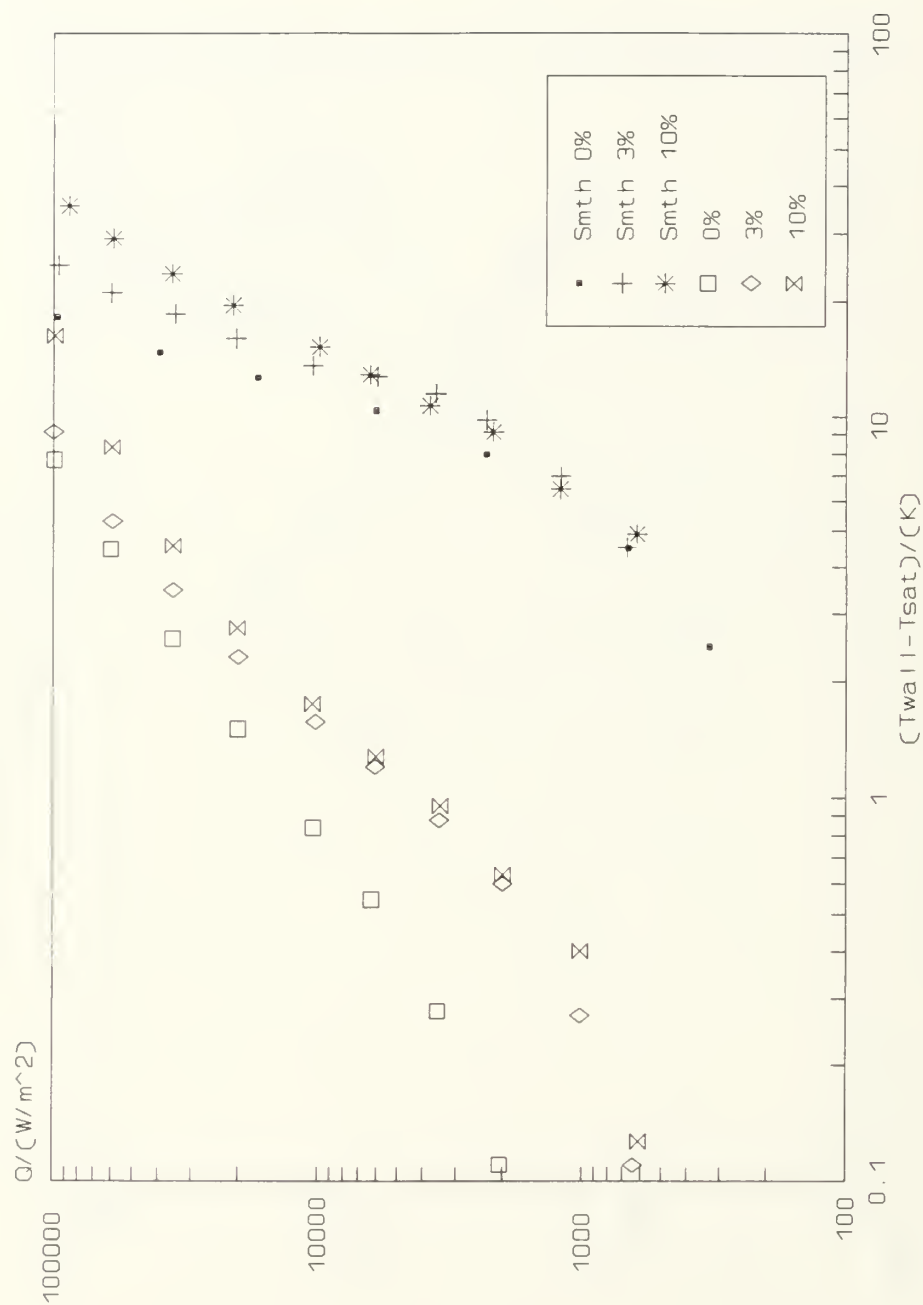
Figure 6.66 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Thermoexcel-HE Tube

122
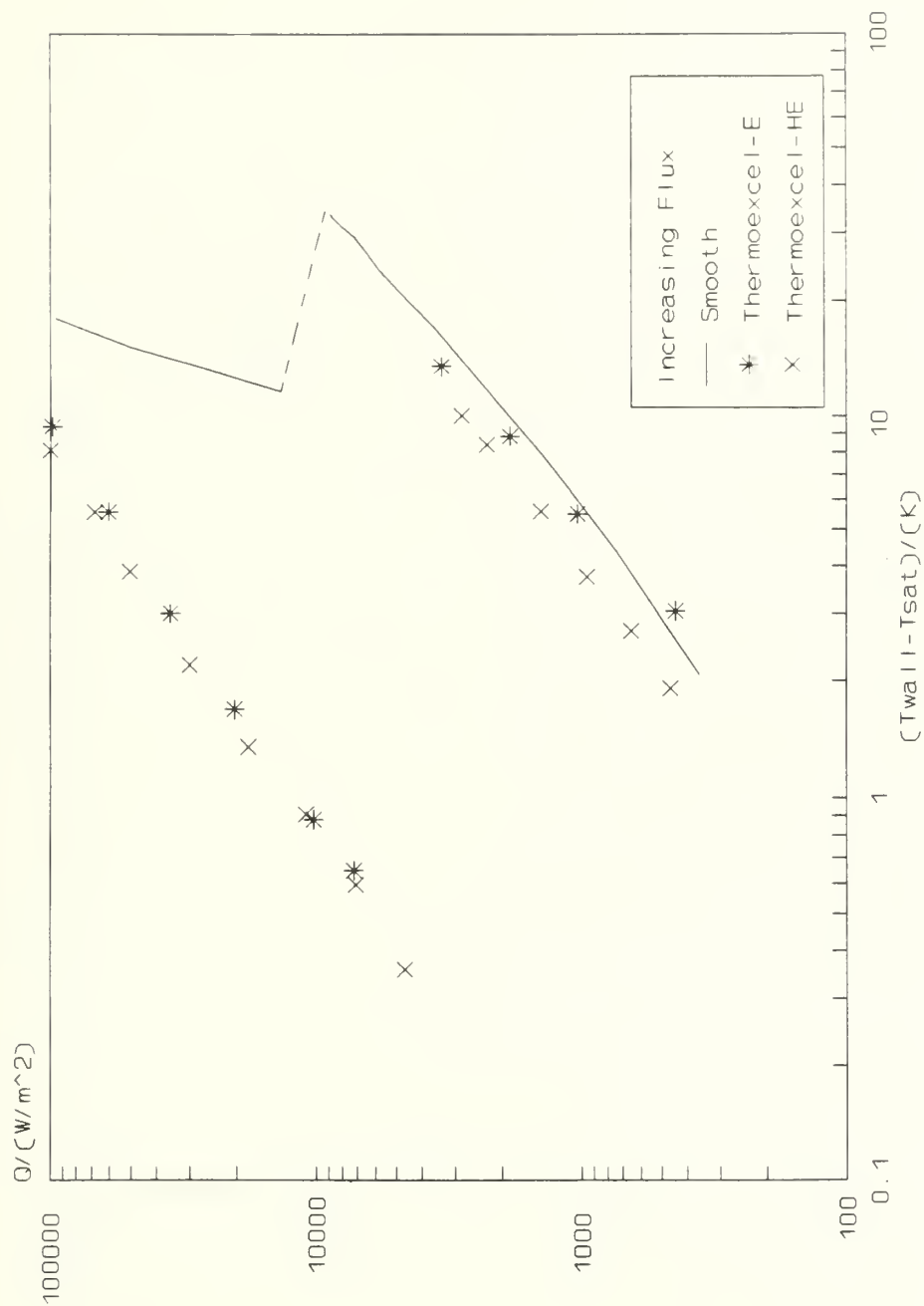
Figure 6.67 Performance Comparison For
Boiling Pure R-114 From
Thermoexcel-E/HE Tubes
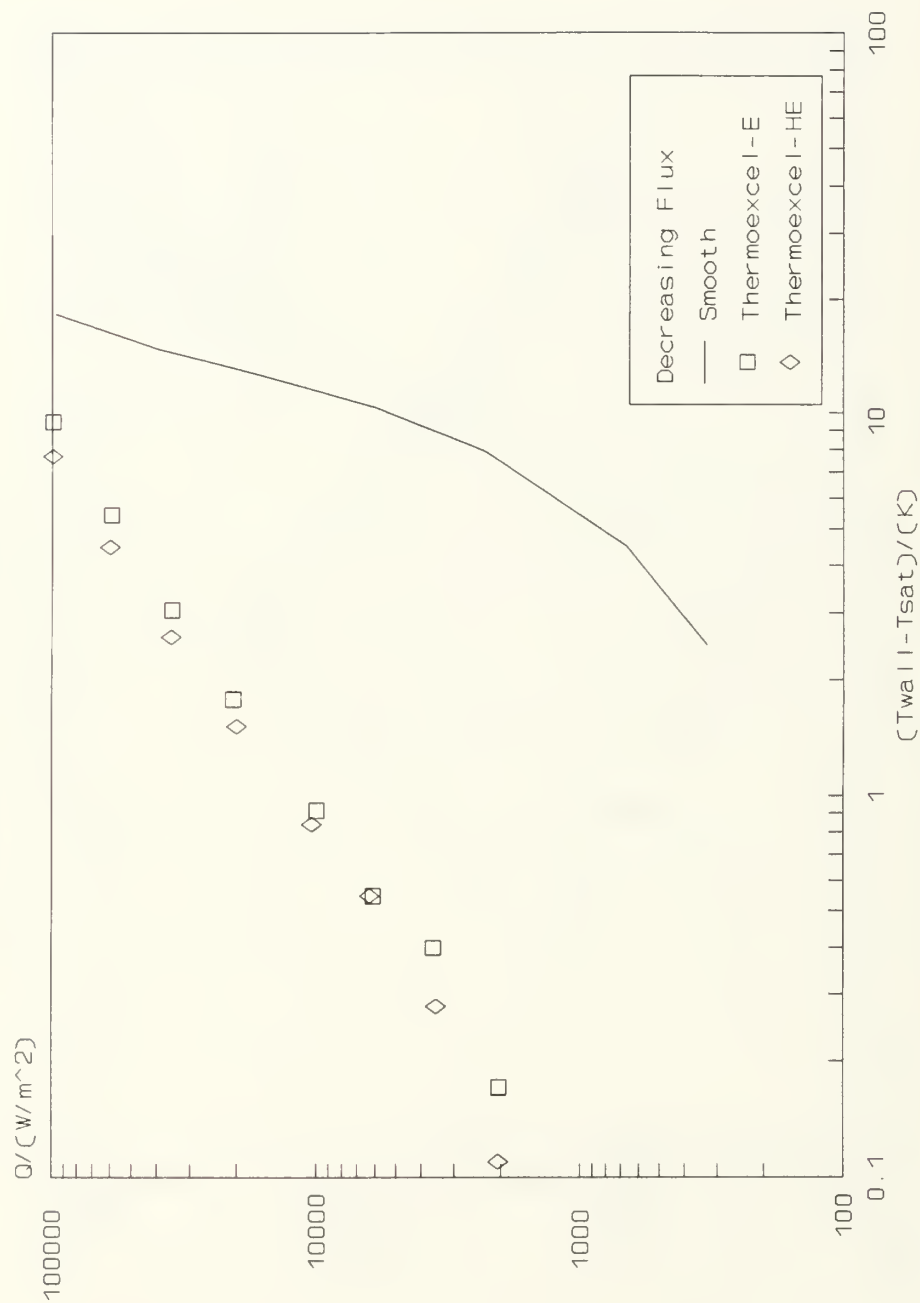
Figure 6.68 Performance Comparison For
Boiling Pure R-114 From
Thermoexcel-E/HE Tubes

124
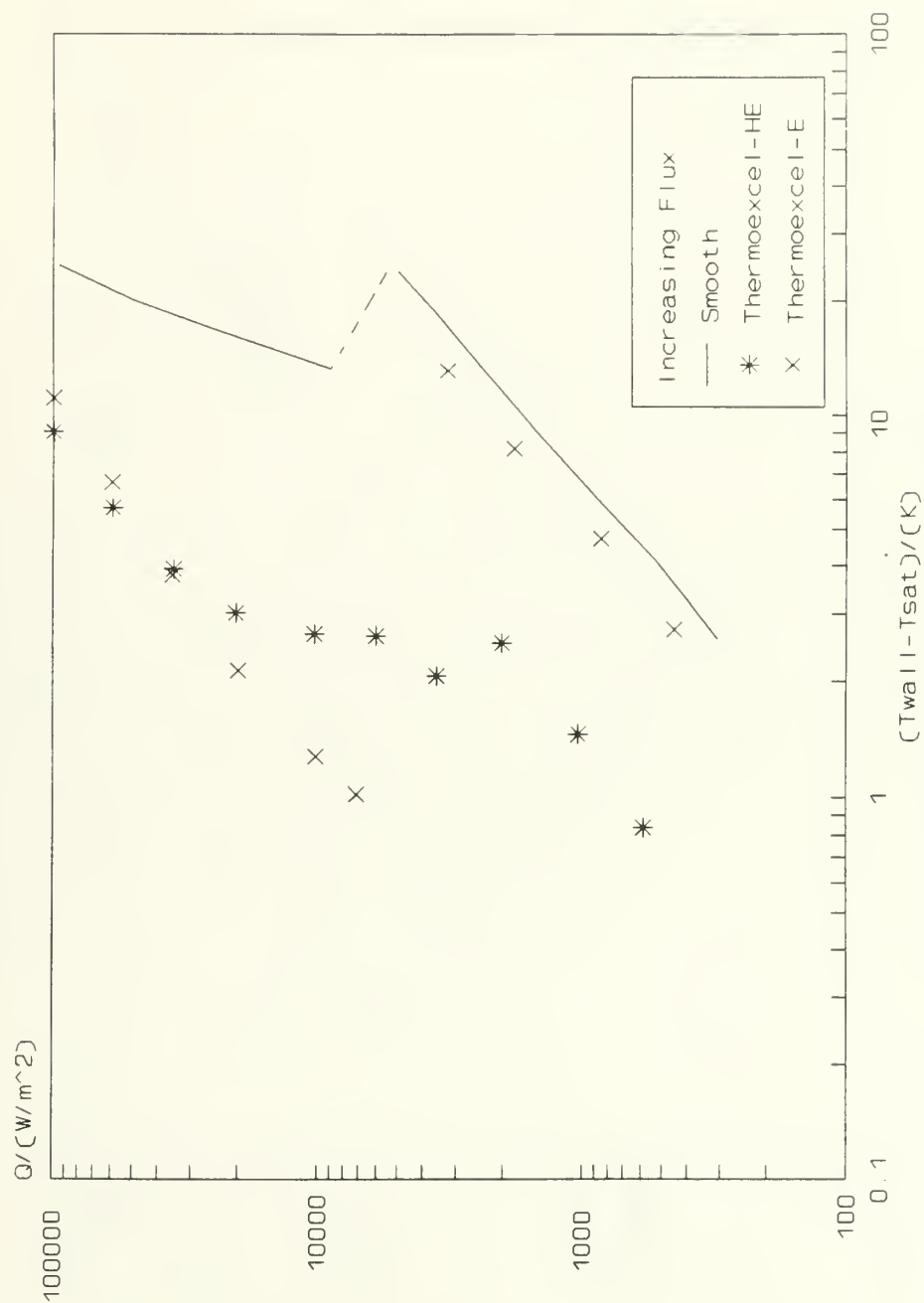
Figure 6.69 Performance Comparison For
Boiling R-114/3% Oil Mixture From
Thermoexcel-E/HE Tubes

Figure 6.70 Performance Comparison For
Boiling R-114/3% Oil Mixture From
Thermoexcel-E/HE Tubes
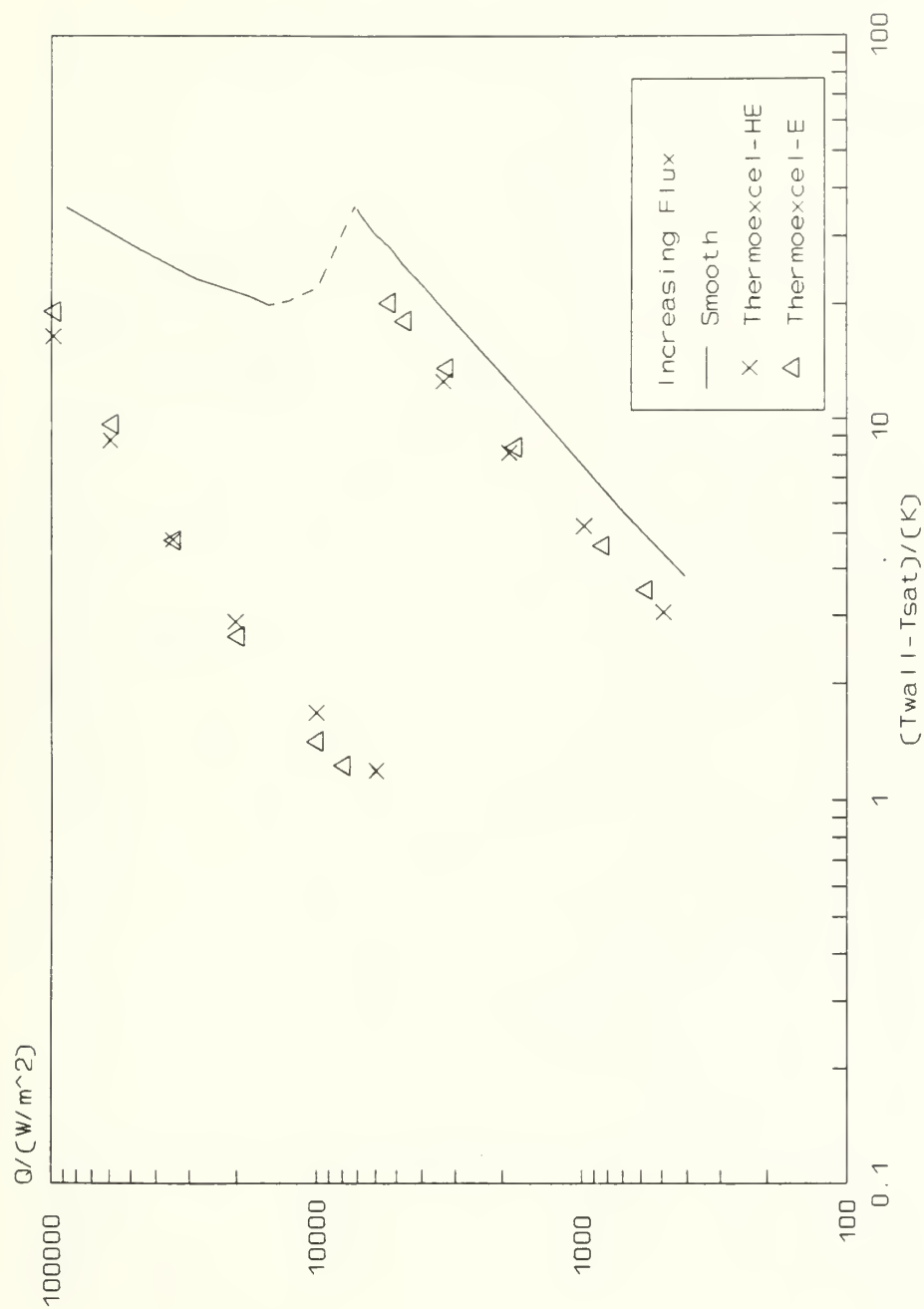
Figure 6.71 Performance Comparison For
Boiling R-114/10% Oil Mixture From
Thermoexcel-E/HE Tubes

127
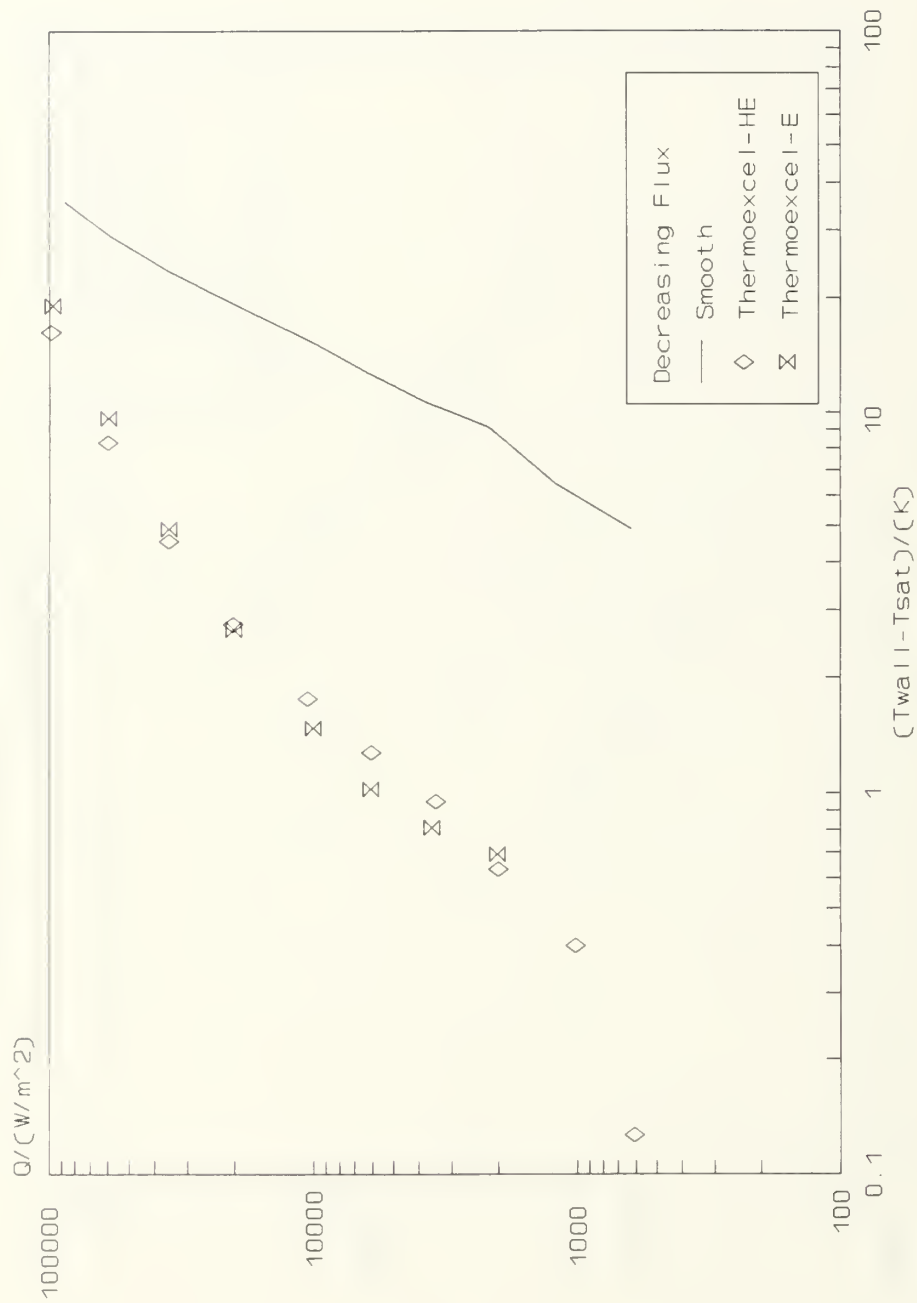
Figure 6.72 Performance Comparison For
Boiling R-114/10% Oil Mixture From
Thermoexcel-E/HE Tubes

128
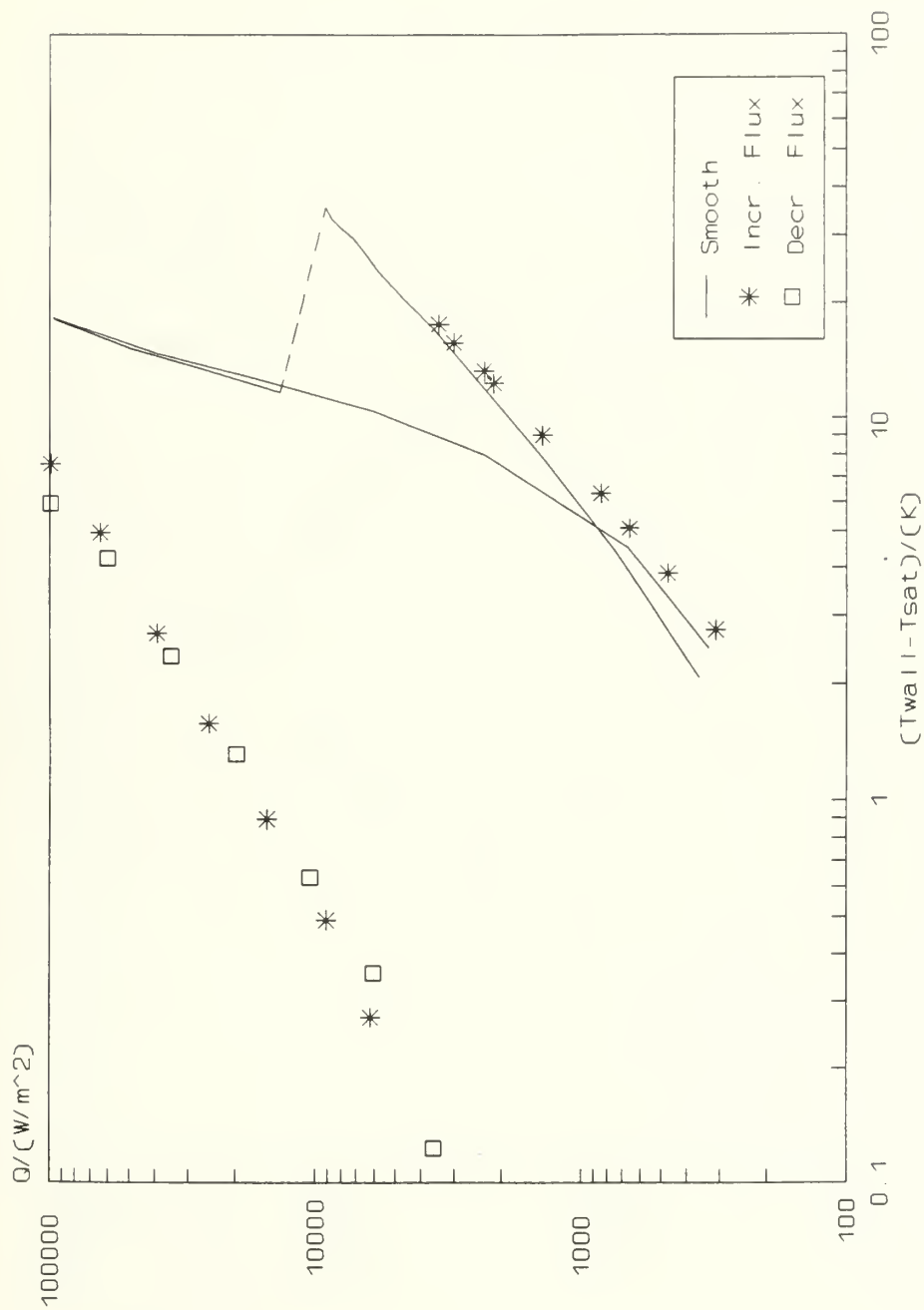
Figure 6.73 Performance Comparison For
Pure R-114 Boiling From
Turbo-B Tube

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Figure 6.74 Performance Comparison For
Boiling R-114/3% Oil Mixture From
Turbo-B Tube
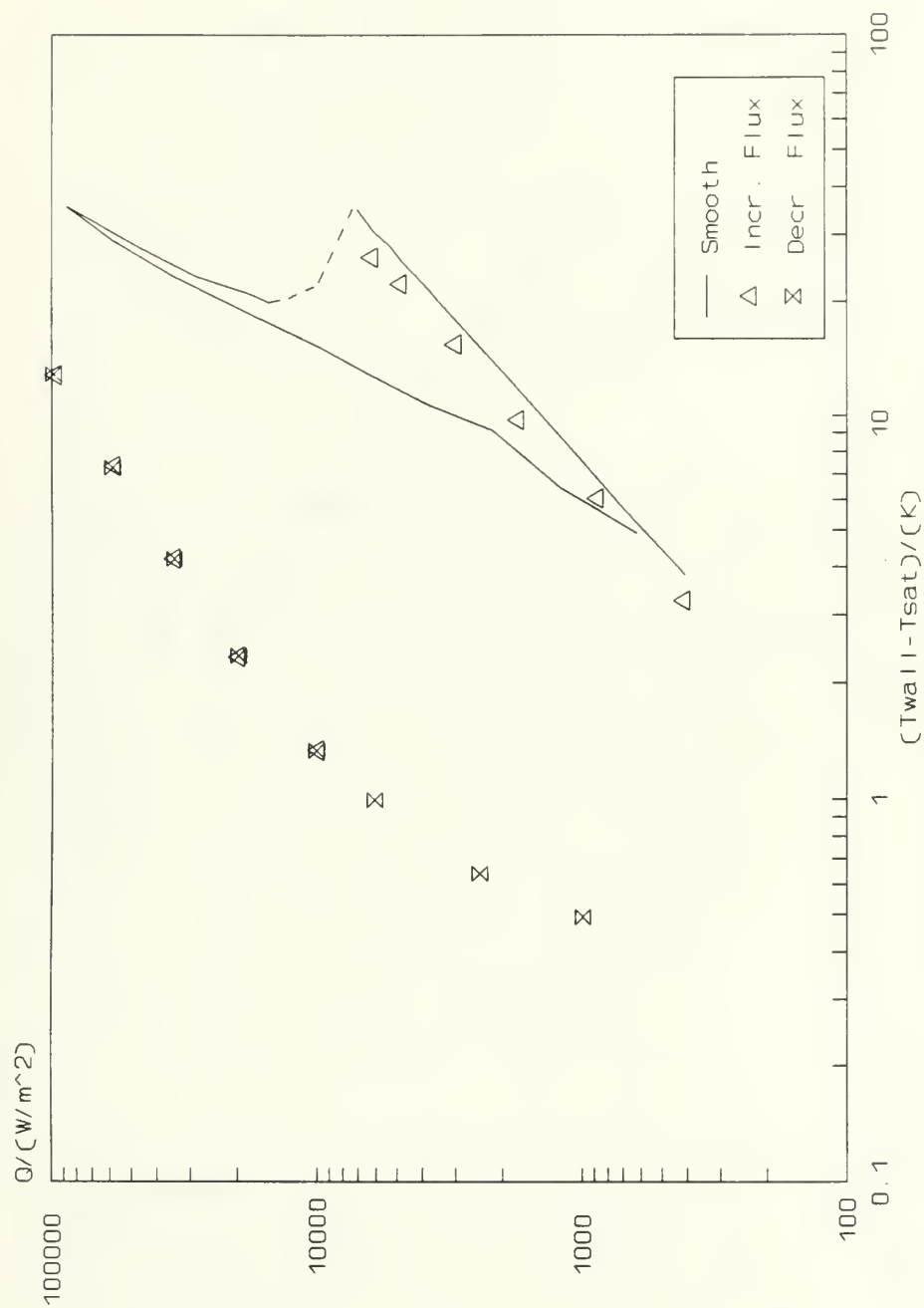
Figure 6.75 Performance Comparison For Boiling R-114/10% Oil Mixture From Turbo-B Surface

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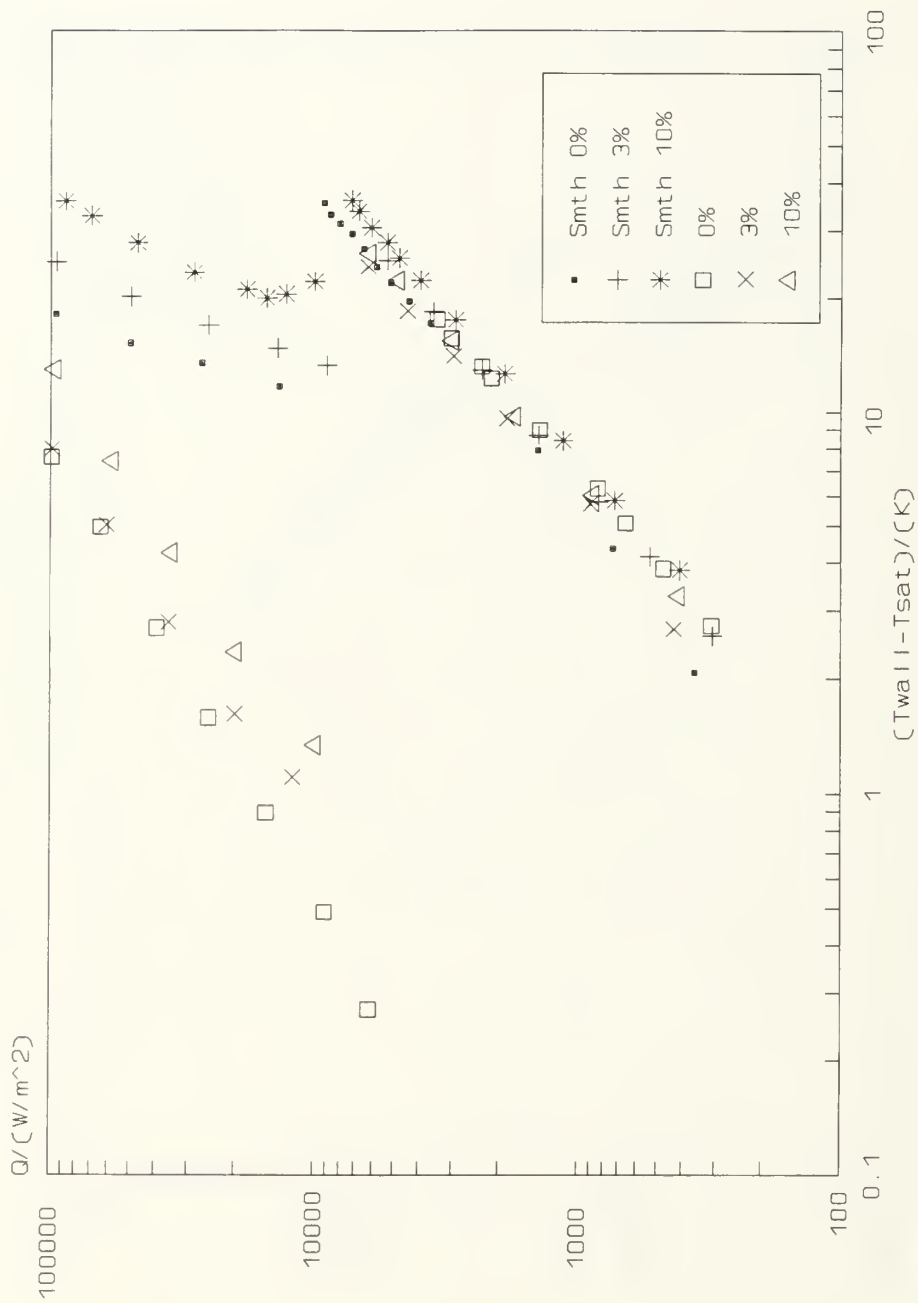
Figure 6.76 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Increasing Flux From Turbo-B Tube

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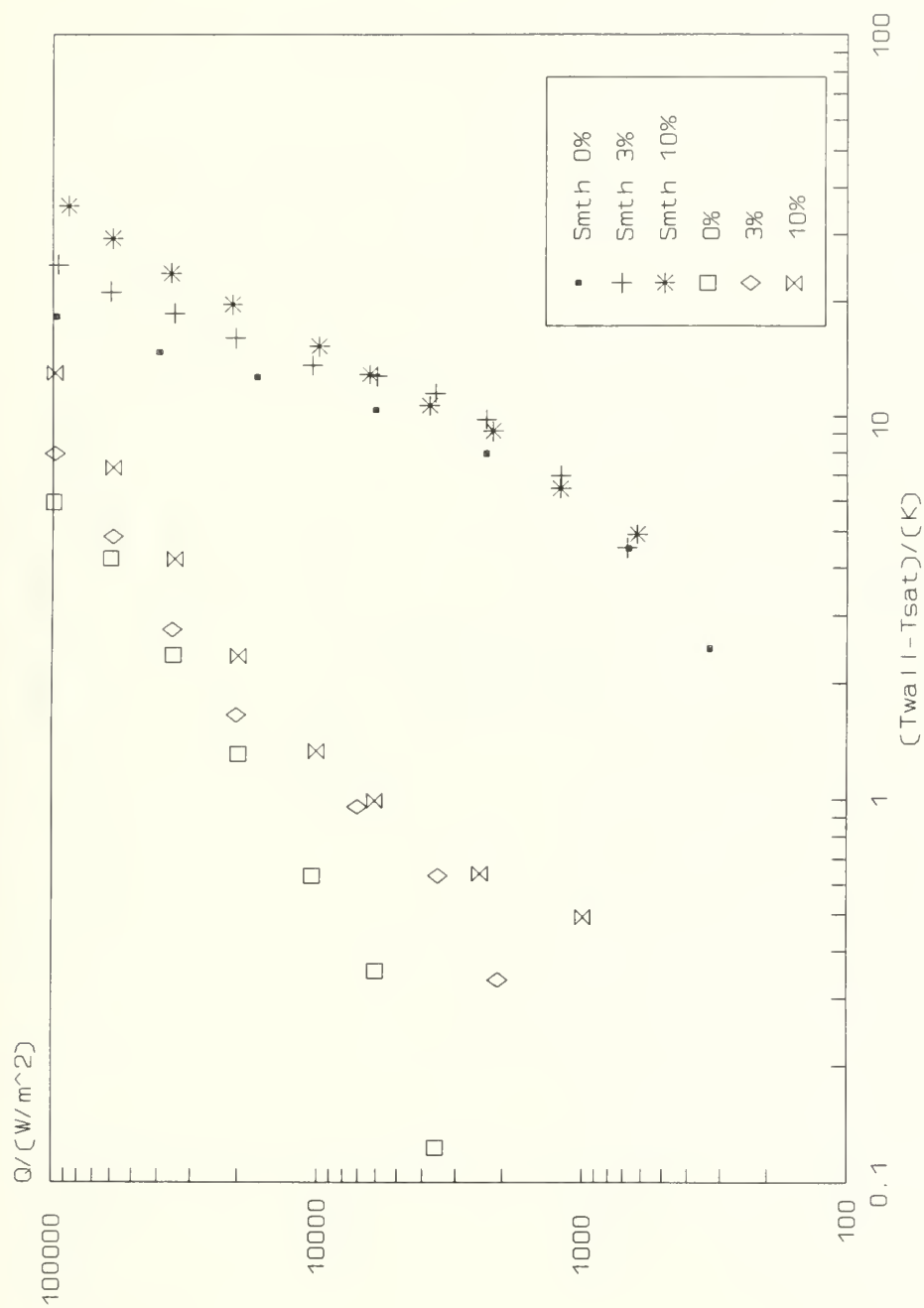
Figure 6.77 Performance Comparison For
Boiling R-114/ 0%, 3% & 10% Oil Mixtures
Decreasing Flux From Turbo-B Tube
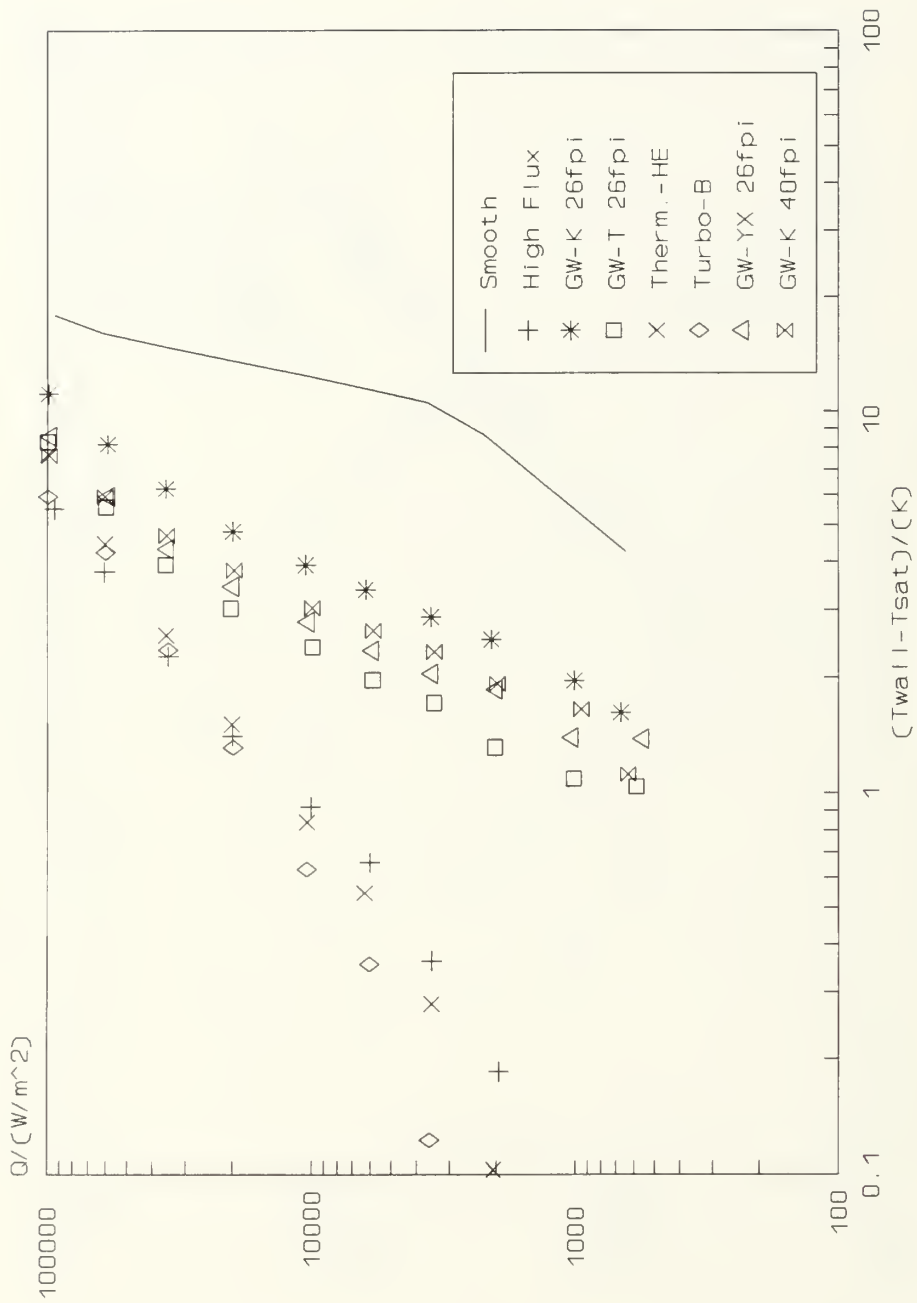
Figure 6.78 Performance Comparison For
Boiling Pure R-114 Boiling From
Smooth and Enhanced Tubes

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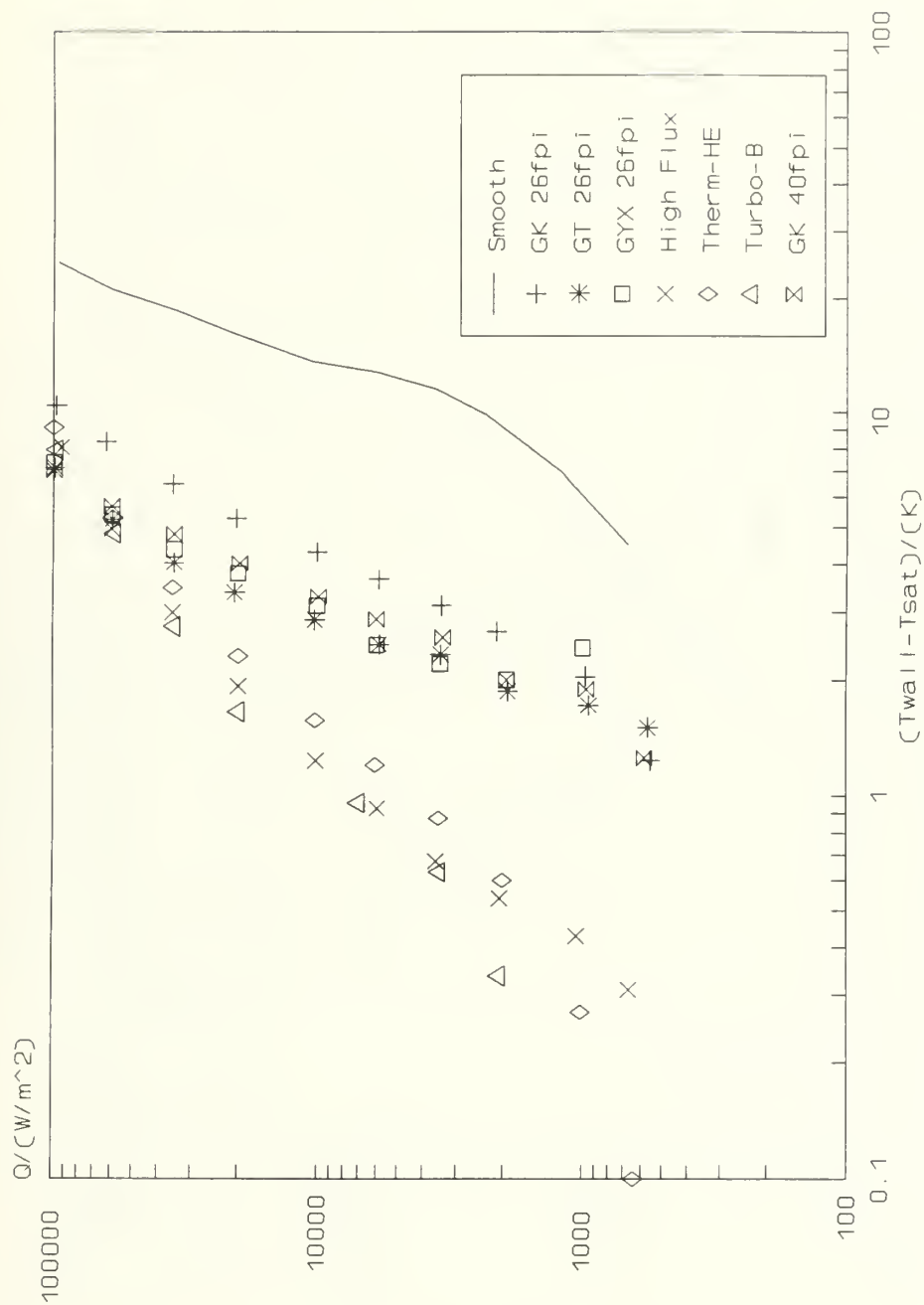
Figure 6.79 Performance Comparison For Boiling R-114/3% Oil Mixture From Smooth and Enhanced Tubes
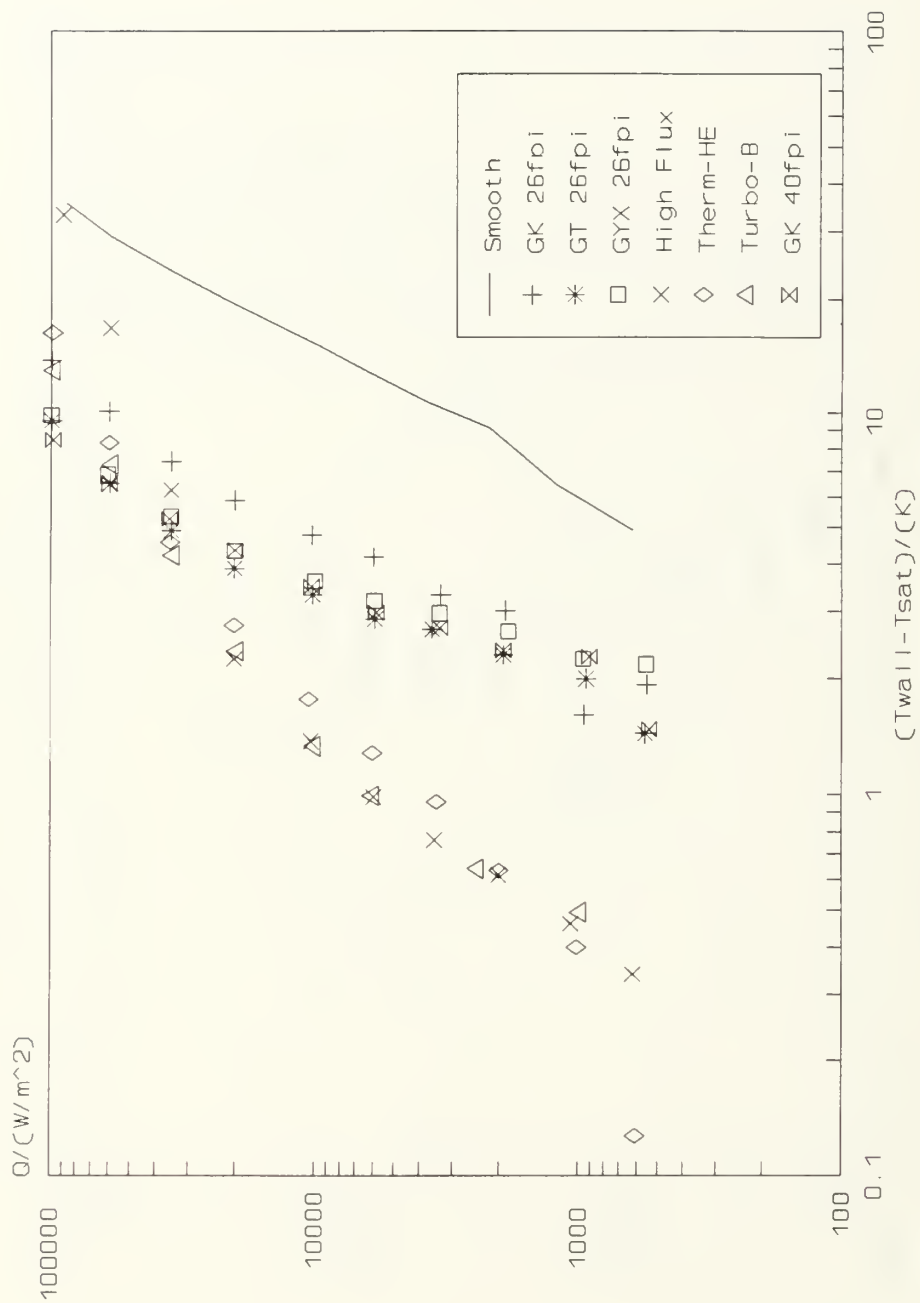
Figure 6.80 Performance Comparison For
Boiling R-114/10% Oil Mixture From
Smooth and Enhanced Tubes

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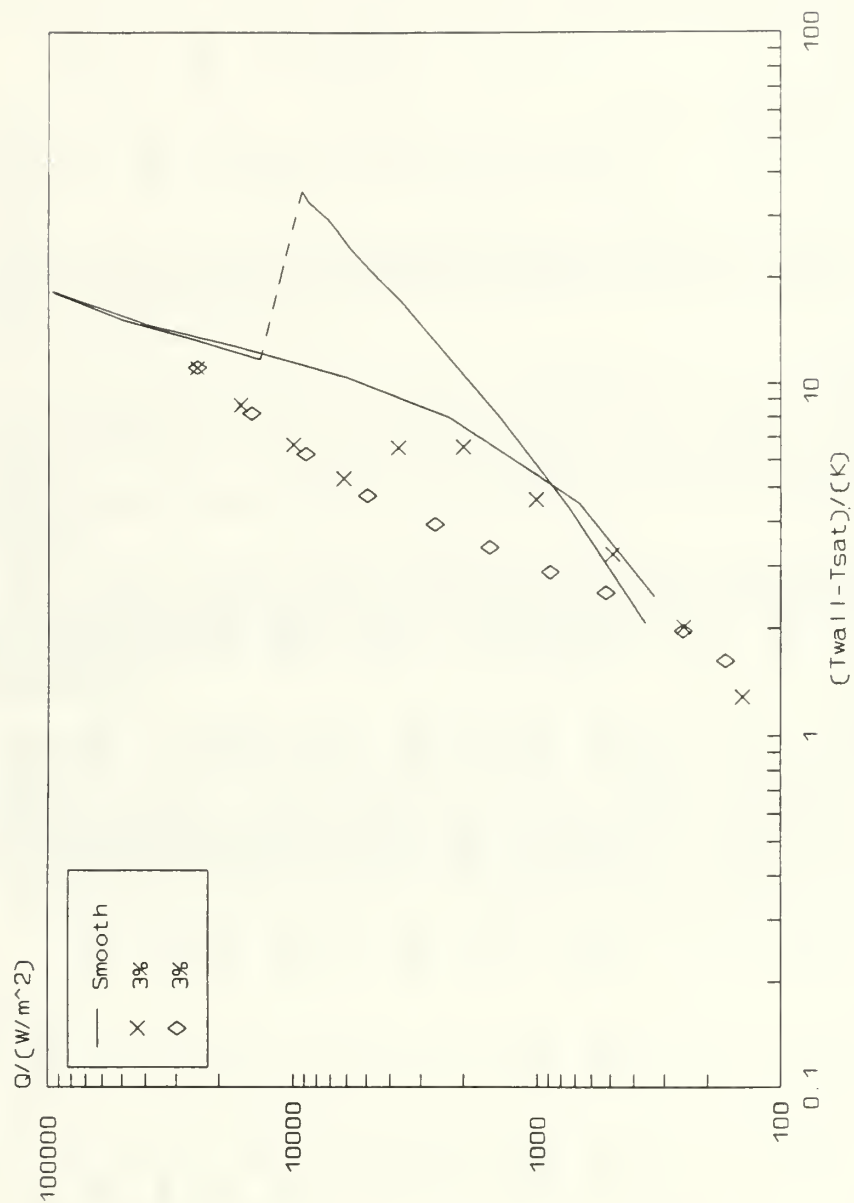
Figure 6.81 Performance Comparison For
Pure R-114 Boiling From GEWA-K 26 fpi
Using Actual Wetted Surface Area

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Heat Flux /(kW/m^2)	3.5			10			35			100		
Oil Conc. /(%)	0	3	10	0	3	10	0	3	10	0	3	10
Tube Type												
Smooth	1	1	1	1	1	1	1	1	1	1	1	1
GK-26fpi	3.6	3.8	3.2	3.1	3.1	3.3	2.4	2.9	3.2	1.6	2.4	2.6
GK-40fpi	4.6	4.4	4	4.1	4.1	4.4	3.1	3.9	4.6	2.4	3.6	4.2
GT-19fpi	6.6	6.1	5.3	5.4	5.4	5.7	3.1	4.3	5.2	1.8	3	3.5
GT-26fpi	6.2	5	3.9	5.2	4.7	4.6	3.7	4.6	4.8	2.2	3.5	3.7
GX-26fpi	5.3	5.2	3.5	4.4	4.4	4.3	3.4	4.3	4.4	2.1	3.4	3.6
High Flux	30.9	17.2	13.6	13.5	11.3	10.9	6.4	6.2	3.8	3.3	3.1	1.1
T-HE	26.3	17.4	12.8	13.6	10.5	10.2	4.8	5.1	4.8	1.9	2.2	1.9
T-E	38.9	13.1	10.9	14.6	8.5	8.5	5.7	5.3	5.2	2.6	2.7	2.2
Turbo-B	105	18	14.2	19.4	12.1	11.8	6.2	6.7	5.6	3.1	3.1	2.7

GK = GEWA-K GT = GEWA-T GX = GEWA-YX T-HE = Thermoexcel-HE T-E = Thermoexcel-E

TABLE III. HEAT TRANSFER COEFFICIENT ENHANCEMENT RATIOS FOR SMOOTH VERSUS ENHANCED SURFACES

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VII. CONCLUSIONS

1. Accurate and repeatable boiling heat-transfer data using R-114 and R-114/oil mixtures was obtained on ten enhanced tube surfaces.

2. Three distinct groups of boiling tubes can be identified by structure and boiling performance: smooth, finned and reentrant cavity.

3. Significant increase in performance was observed for reentrant cavity surfaces versus either the finned or smooth surfaces within the nucleating regime at all heat fluxes tested.

4. Degradation in boiling performance accompanied increases in oil concentration within the nucleating regime. Most notably, the high flux surface performed comparably to a smooth surface at the highest flux tested.

5. Within the convection regime all tube surfaces tested performed equally well. No significant effect of oil concentration can be observed up to incipient nucleation.

6. Distinct temperature overshoot within the convection regime occurs repeatably in all tube surfaces tested. The reentrant cavity surfaces exhibit the most extreme overshoot versus either the finned or smooth surfaces. Oil concentration has no significant effect.

VIII. RECOMMENDATIONS

1. Due to the way a real flooded evaporator operates, it would be preferable to heat the tube within the single tube apparatus with hot water.

2. As a complement to present single tube and bundle tube studies, the present single tube apparatus should be modified to accommodate two vertically aligned boiling tubes in order to study the effects of multiple tubes and variation of tube pitch to diameter ratios.

3. The physical properties of the R-114/oil mixtures tested should be measured for comparison to the predictions used in the data reduction program and for better understanding of the mechanisms driving the degradation in heat transfer performance.

4. Neutrally buoyant particles should be placed in the pool to facilitate study of the circulation patterns within the flooded evaporator in more detail.

5. A high speed camera should be used to study the nucleation process and circulation patterns in more detail.

APPENDIX A: THERMOPHYSICAL PROPERTIES OF R-114

The following thermophysical properties of saturated R-114 are plotted versus temperature °C:

1.	Liquid Density (kg/m^3)
2.	Liquid Dynamic Viscosity (Pa*s)
3.	Liquid Thermal Conductivity (W/m*K)
4.	Liquid Specific Heat (J/kg*K)
5.	Latent Heat (J/kg)
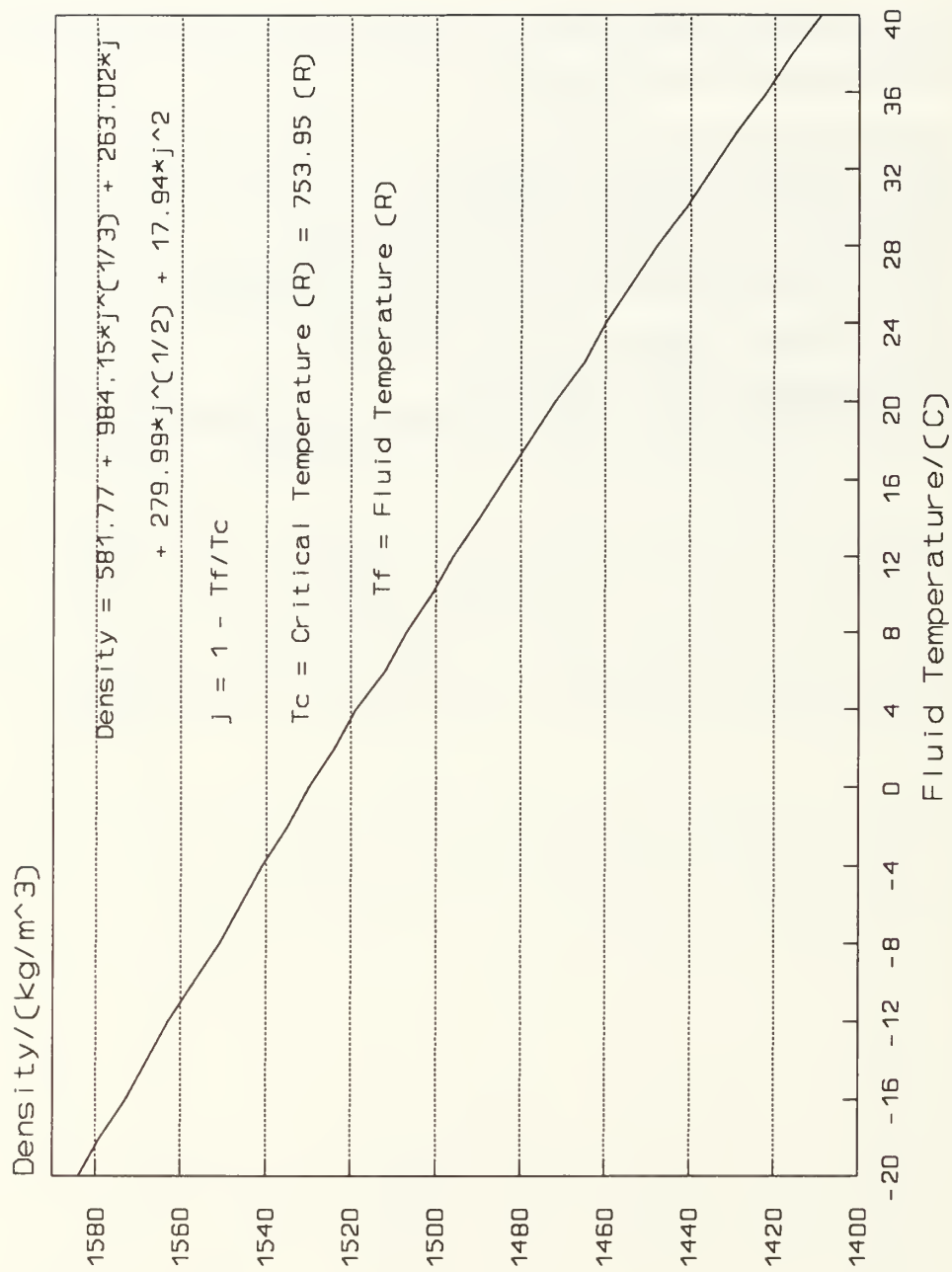
Figure A.1 Density of R-114

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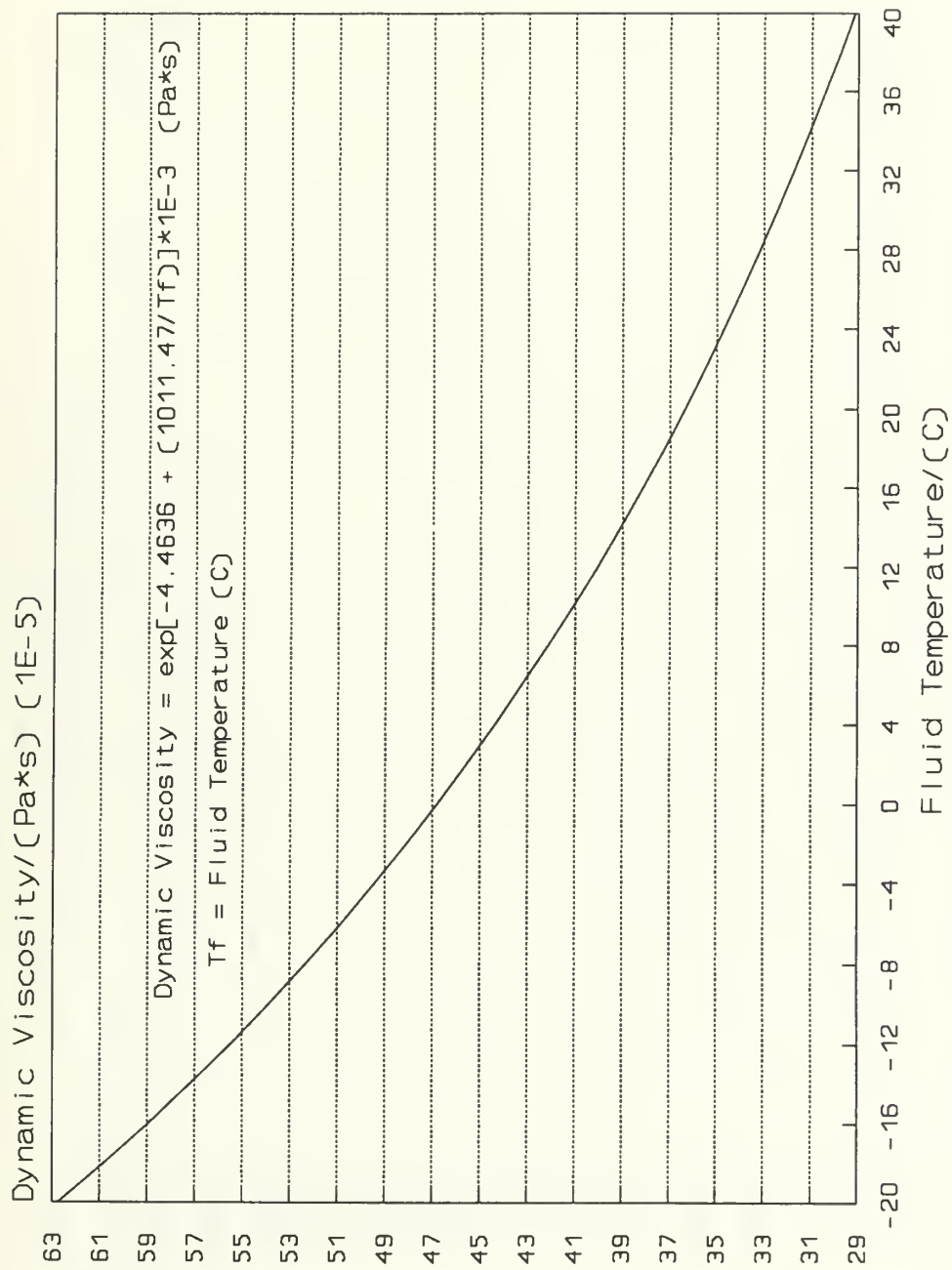
Figure A.2 Dynamic Viscosity of R-114
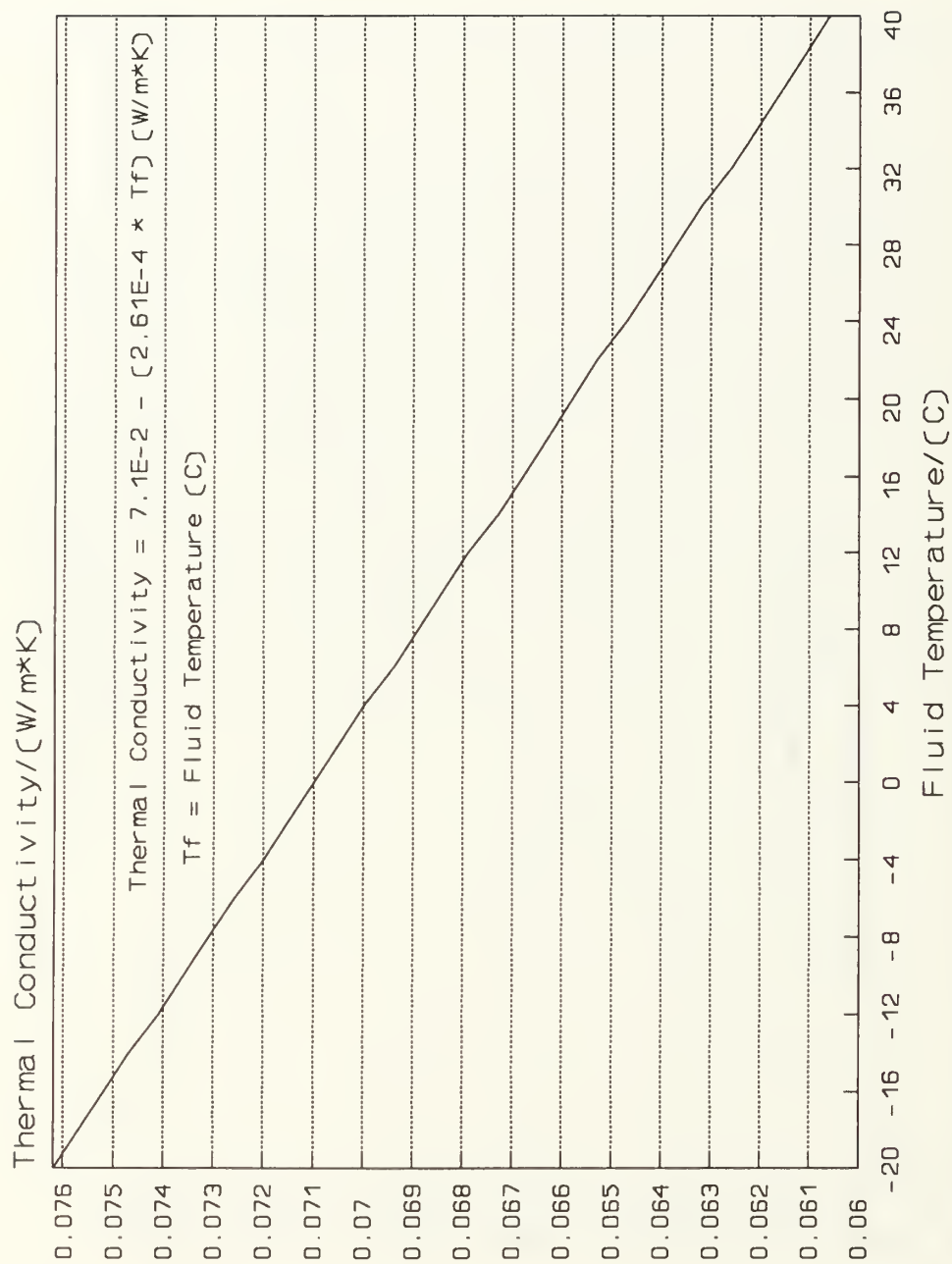
Figure A.3 Thermal Conductivity of R-114

Thermal Conductivity/(W/m*K)

Thermal Conductivity = 7.1E-2 - (2.61E-4 * Tf) (W/m*K)

Tf = Fluid Temperature (C)

Fluid Temperature/(C)

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Specific Heat/(J/kg*K)

Specific Heat = 400 + (1.65 * Tf) + (1.51E-3 * Tf^2)

        - (6.68E-7 * Tf^3)   (J/kg*K)

Tf = Fluid Temperature (C)

Fluid Temperature/(C)
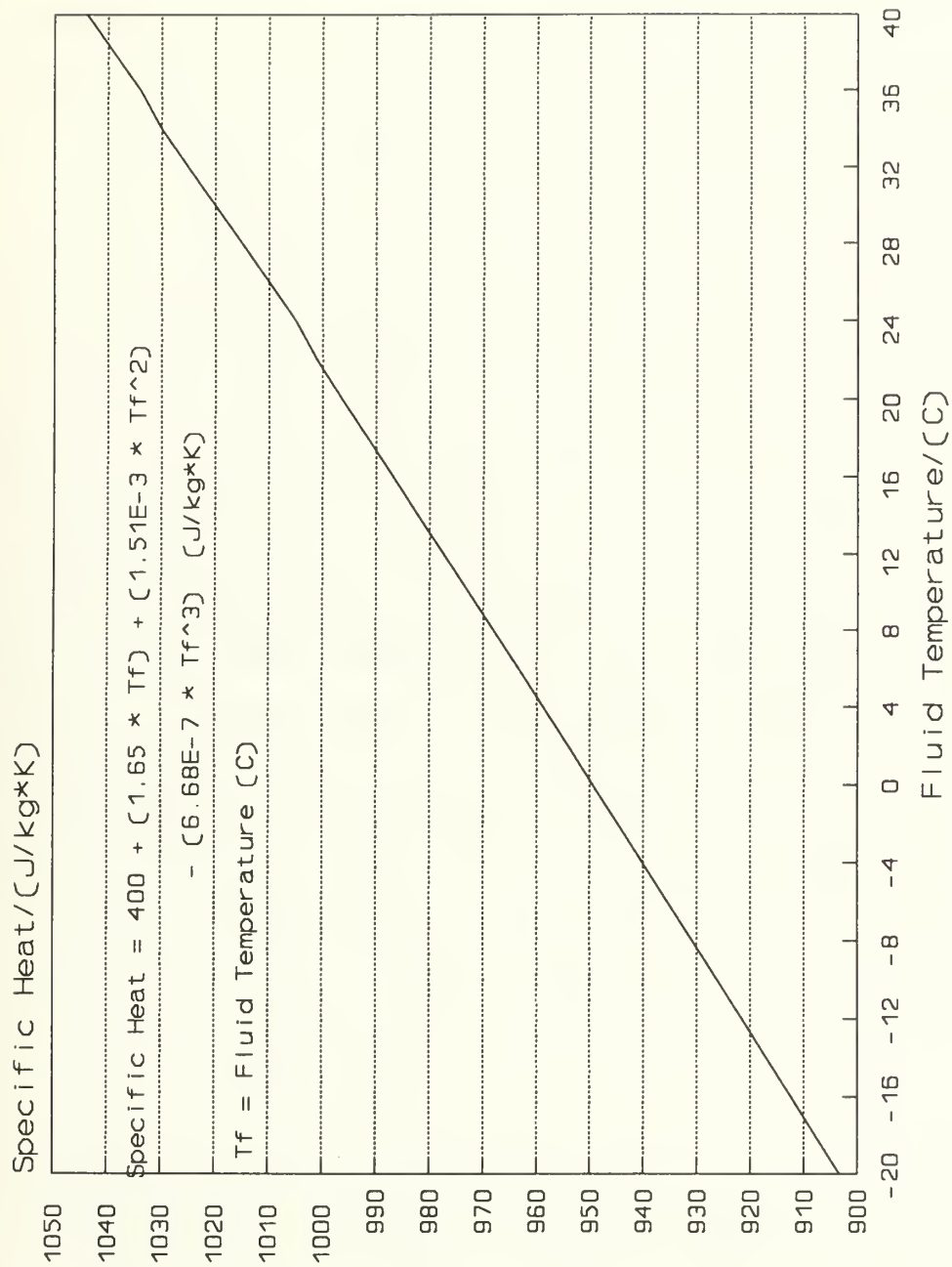
Figure A.4   Specific Heat of R-114

Figure A.5 Latent Heat of R-114

APPENDIX B: DATA ACQUISITION APPARATUS CALIBRATION

A. BACKGROUND

Early data runs revealed a disparity in calculated values between previously reported theses and those presently obtained for heat flux and heat-transfer coefficients. The thermocouple channels were checked for validity of temperature readings using other programs and data acquisition equipment. Their readings were found to be as accurate as possible (± 3%). Voltage readings originating from the RMS converter were also checked out as accurate. The RMS converter converts true voltage measured into a proportional voltage output (0-10 volts) to the data acquisition unit. The proportionality constant to convert RMS voltage readings, Vs, to real tube heater voltage, V, was equal to 25. This was verified using a standard voltmeter across the power leads of the cartridge heater measured over several power settings. The discrepancy was identified to be the measurement of the current supplied to the tube cartridge heater by the VARIAC unit as measured by the inductive pickup (Figure 3.13). The inductive measurement of current (in proportional volts) is no longer run through the RMS converter. Instead, it is run directly to the Data Acquisition Unit. A procedure to measure the true current and calculate the proportionality constant for converting the

inductive current, Is, to the true current, I, was established
as follows:

B. EQUIPMENT USED

1.   Voltmeter

2.   2 ohm resistor

3.   HP-3852A Data Acquisition Unit

4.   Computer - HP-9300 Series

5.   Current Sensor (Inductive Pickup)

6.   Voltage Sensor/RMS Converter

7.   Cartridge Heater - 1kW, 220V rating

8.   VARIAC - power supply 220V AC

9.   SETUP8 program

C. CALIBRATION PROCEDURE

1.   Ensure all power is turned off to the VARIAC.

2.   Insert the standard 2 ohm resistor in series with the
     cartridge heater as shown in Figure C.1.

3.   Connect leads of voltmeter across the 2 ohm resistor to
     measure the drop in voltage. At any given power
     setting, the current through the resistor will equal
     the current through the cartridge heater. This assumes
     the resistances of both heater and resistor are
     constant. This was verified as shown in Figure C.2. The
     total resistance of the heater/resistor rapidly and
     asymptotically approached a constant value.

4.   Connect power to the VARIAC.

5.   Load and run SETUP8 program to provide the voltage and
     current readings made by the data acquisition unit.
     Note the SETUP8 program used in calibration differed

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from that listed in Appendix G. A proportionality constant of 2.0 was assumed for calibration then modified once the true value was calculated.

6. Starting with the VARIAC set at zero volts, incrementally increase the voltage up to the maximum of 220V.

7. At each voltage, measure the drop in voltage across the resistor. The current (amps) is calculated:
    I = Drop in voltage (volts) / 2 ohms

8. Note and compare the current provided by the program.

9. At the maximum 220V, incrementally decrease voltage down to 0, taking comparative current readings as before, in order to detect any hysteresis effect. None was observed.

10. Plot current (amps) vs. voltage (volts). See Figure C.3. Note the linearity of both data sets. The true meter reading is some factor smaller than the data acquisition readings.

11. The calibration constant, C, is calculated by:
    $$C = \frac{(\Sigma \text{ Meter current})}{(\Sigma \text{ Data acquisition current})} * 2$$
    C = 1.9182

D. DISCUSSION

A disparity between the previous reported theses values and those presently obtained still exists. Calculated values reported in previous theses for the heat flux and the heat transfer coefficient are consistently higher. No previous thesis reports such a calibration as carried out above and it is thought that this is the cause of the discrepancy.
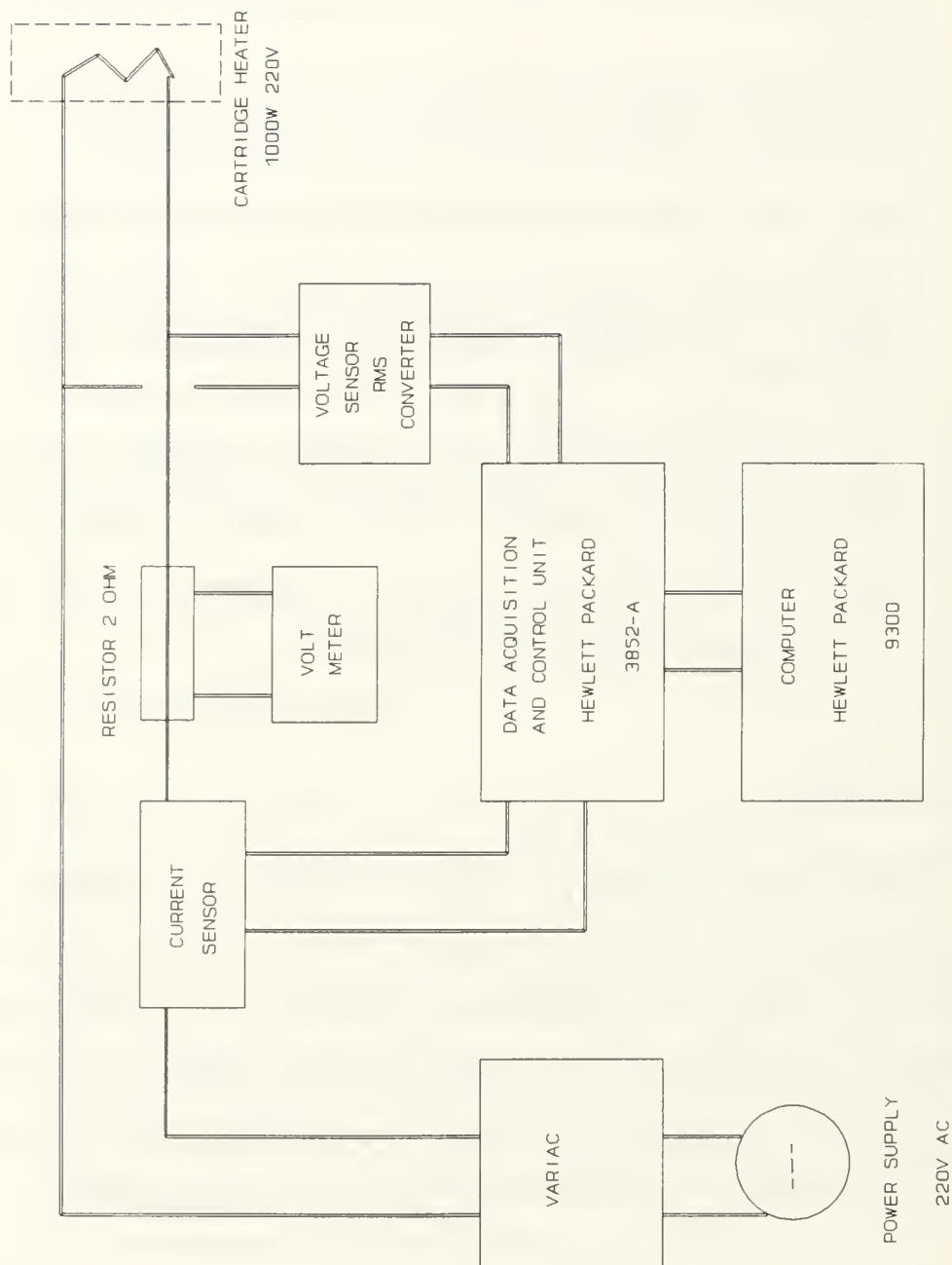
Figure B.1 Schematic of Calibration Setup

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Figure B.2 Cartridge Heater Resistence
For High Flux Tube

Current/(amperes)

Data Acquisition Current

Meter Current
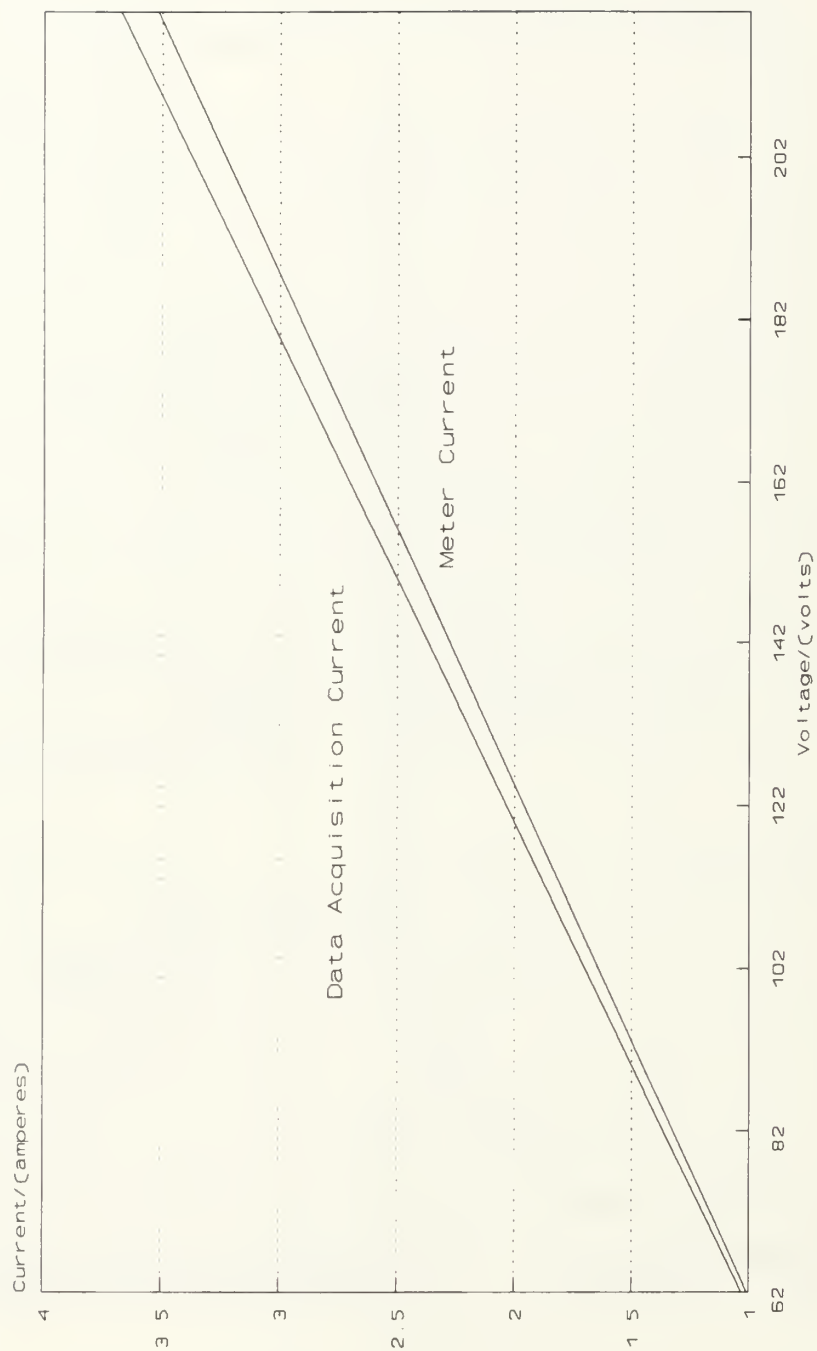
Figure 8.3 Variac Current Calibration
Using High Flux Tube

Voltage/(volts)

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APPENDIX C: AN EXAMPLE OF REPRESENTATIVE DATA RUN

```
Month, date and time : 5 Jul 1991       17:21:51

NOTE: Program name : DRP8
      Disk number  = 01
      New file name: DATA070515
      TC is defective at location  2
      Tube Number:   5

Data Set Number =    1 Bulk Oil % =   0.0     2.11545538805
TC No:     1      2      3      4      5      6      7      8
Temp :   5.11   0.00   5.15   5.01   5.12   5.08   5.09   5.11
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 5.08   2.36   2.26   3.91  -1.65  -13.8
 Thetab Htube      Qdo
 2.770  1.590E+02  4.406E+02

Data Set Number =    2 Bulk Oil % =   0.0     2.11545539033
TC No:     1      2      3      4      5      6      7      8
Temp :   4.94   0.00   5.04   4.87   4.99   4.95   4.96   4.98
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 4.95   2.23   2.18   3.29  -1.76  -13.7
 Thetab Htube      Qdp
 2.740  1.603E+02  4.391E+02

Data Set Number =    3 Bulk Oil % =   0.0     2.11545539756
TC No:     1      2      3      4      5      6      7      8
Temp :   6.08   0.00   6.19   5.96   6.14   6.09   6.11   6.15
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 6.07   2.38   2.16   3.27  -1.69  -13.6
 Thetab Htube      Qdp
 3.806  1.694E+02  6.446E+02

Data Set Number =    4 Bulk Oil % =   0.0     2.11545539780
TC No:     1      2      3      4      5      6      7      8
Temp :   6.12   0.00   6.23   6.02   6.18   6.14   6.15   6.18
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 6.12   2.39   2.19   3.29  -1.67  -13.6
 Thetab Htube      Qdp
 3.828  1.682E+02  6.439E+02

Data Set Number =    5 Bulk Oil % =   0.0     2.11545540628
TC No:     1      2      3      4      5      6      7      8
Temp :   7.13   0.00   7.27   6.97   7.24   7.15   7.17   7.25
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 7.13   2.24   2.16   2.92  -1.77  -13.6
 Thetab Htube      Qdp
 4.934  1.791E+02  8.834E+02

Data Set Number =    6 Bulk Oil % =   0.0     2.11545540655
TC No:     1      2      3      4      5      6      7      8
Temp :   7.09   0.00   7.25   6.95   7.21   7.13   7.15   7.20
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 7.11   2.20   2.12   2.91  -1.81  -13.5
 Thetab Htube      Qdp
 4.945  1.786E+02  8.834E+02

Data Set Number =    7 Bulk Oil % =   0.0     2.11545541023
TC No:     1      2      3      4      5      6      7      8
Temp :   9.56   0.00   9.74   9.36   9.71   9.60   9.62   9.75
 Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 9.57   2.47   2.22   2.94  -1.61  -13.5
 Thetab Htube      Qdp
 7.223  1.863E+02  1.346E+03
```

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```
Data Set Number =   8  Bulk Oil % =   0.0      2.11545541165
TC No:      1       2       3       4       5       6       7       8
Temp :   9.33    0.00    9.52    9.11    9.49    9.37    9.39    9.50
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
  9.33    2.21    2.13    2.82   -1.80   -13.5
  Thetab  Htube       Qdo
  7.165  1.874E+02  1.343E+03

Data Set Number =   9  Bulk Oil % =   0.0      2.11545541546
TC No:      1       2       3       4       5       6       7       8
Temp :  10.99    0.00   11.53   11.09   11.50   11.38   11.40   11.40
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 11.26    2.30    2.16    2.66   -1.73   -13.5
  Thetab  Htube       Qdp
  9.026  1.963E+02  1.772E+03

Data Set Number =  10  Bulk Oil % =   0.0      2.11545541589
TC No:      1       2       3       4       5       6       7       8
Temp :  11.00    0.00   11.52   11.09   11.50   11.37   11.40   11.41
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 11.26    2.32    2.22    2.67   -1.69   -13.5
  Thetab  Htube       Qdp
  8.988  1.977E+02  1.777E+03

Data Set Number =  11  Bulk Oil % =   0.0      2.11545541889
TC No:      1       2       3       4       5       6       7       8
Temp :  11.45    0.00   12.32   11.93   12.30   12.18   12.21   12.10
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 11.99    2.24    2.17    2.67   -1.76   -13.5
  Thetab  Htube       Qdp
  9.783  2.074E+02  2.029E+03

Data Set Number =  12  Bulk Oil % =   0.0      2.11545541913
TC No:      1       2       3       4       5       6       7       8
Temp :  11.50    0.00   12.38   11.97   12.35   12.24   12.25   12.14
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 12.04    2.26    2.19    2.69   -1.74   -13.5
  Thetab  Htube       Qdp
  9.814  2.065E+02  2.027E+03

Data Set Number =  13  Bulk Oil % =   0.0      2.11545542290
TC No:      1       2       3       4       5       6       7       8
Temp :  12.08    0.00   13.11   12.71   13.09   12.98   12.99   12.82
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 12.74    2.22    2.20    2.96   -1.75   -13.5
  Thetab  Htube       Qdp
 10.527  2.112E+02  2.223E+03

Data Set Number =  14  Bulk Oil % =   0.0      2.11545542315
TC No:      1       2       3       4       5       6       7       8
Temp :  12.02    0.00   13.05   12.67   13.03   12.92   12.94   12.75
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 12.68    2.20    2.17    2.96   -1.78   -13.5
  Thetab  Htube       Qdp
 10.494  2.110E+02  2.214E+03

Data Set Number =  15  Bulk Oil % =   0.0      2.11545542511
TC No:      1       2       3       4       5       6       7       8
Temp :  12.55    0.00   13.83   13.53   13.82   13.72   13.73   13.43
  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump
 13.42    2.19    2.16    2.92   -1.79   -13.5
  Thetab  Htube       Qdp
 11.239  2.182E+02  2.452E+03
```

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```
Data Set Number = 16  Bulk Oil % =  0.0    2.11545542534
TC No:    1      2      3      4      5      6      7      8
Temp : 12.62   0.00  13.85  13.61  13.83  13.75  13.75  13.47
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
 13.46   2.26   2.22   2.91  -1.72  -13.5
  Thetab Htube      Qdp
 11.217  2.183E+02  2.449E+03


Data Set Number = 17  Bulk Oil % =  0.0    2.11545543206
TC No:    1      2      3      4      5      6      7      8
Temp :  2.89   0.00   2.74   2.69   2.69   2.59   2.57   2.68
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.58   2.44   2.19   2.01  -1.64  -13.5
  Thetab Htube      Qdp
  .270  1.126E+04  3.036E+03


Data Set Number = 18  Bulk Oil % =  0.0    2.11545543229
TC No:    1      2      3      4      5      6      7      8
Temp :  2.86   0.00   2.71   2.66   2.67   2.56   2.55   2.65
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.56   2.39   2.15   1.98  -1.69  -13.5
  Thetab Htube      Qdp
  .288  1.052E+04  3.029E+03


Data Set Number = 19  Bulk Oil % =  0.0    2.11545543435
TC No:    1      2      3      4      5      6      7      8
Temp :  3.15   0.00   2.97   2.92   2.92   2.79   2.75   2.91
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.76   2.41   2.17   2.09  -1.67  -13.5
  Thetab Htube      Qdp
  .472  9.576E+03  4.523E+03


Data Set Number = 20  Bulk Oil % =  0.0    2.11545543508
TC No:    1      2      3      4      5      6      7      8
Temp :  3.12   0.00   2.93   2.89   2.89   2.75   2.72   2.88
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.73   2.47   2.19   2.08  -1.62  -13.5
  Thetab Htube      Qdp
  .394  1.144E+04  4.506E+03


Data Set Number = 21  Bulk Oil % =  0.0    2.11545543579
TC No:    1      2      3      4      5      6      7      8
Temp :  3.02   0.00   2.83   2.79   2.79   2.64   2.62   2.77
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.62   2.37   2.09   1.98  -1.74  -13.5
  Thetab Htube      Qdp
  .394  1.149E+04  4.525E+03


Data Set Number = 22  Bulk Oil % =  0.0    2.11545543829
TC No:    1      2      3      4      5      6      7      8
Temp :  3.45   0.00   3.20   3.16   3.15   2.96   2.91   3.14
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.89   2.41   2.16   2.76  -1.67  -13.5
  Thetab Htube      Qdp
  .603  1.178E+04  7.099E+03


Data Set Number = 23  Bulk Oil % =  0.0    2.11545543855
TC No:    1      2      3      4      5      6      7      8
Temp :  3.44   0.00   3.19   3.15   3.14   2.96   2.90   3.13
  Twa    Tliqd  Tliqd2 Tvapr  Psat   Tsump
  2.88   2.39   2.15   2.87  -1.69  -13.5
  Thetab Htube      Qdp
  .612  1.158E+04  7.092E+03
```

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```
Data Set Number = 24  Bulk Oil % =  0.0      2.11545544709
TC No:    1      2      3      4      5      6      7      8
Temp :  3.95   0.00   3.56   3.55   3.50   3.29   3.20   3.52
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.12   2.36   2.17   2.71  -1.69  -13.6
 Thetab Htube      Qdo
  .857  1.279E+04  1.096E+04

Data Set Number = 25  Bulk Oil % =  0.0      2.11545544732
TC No:    1      2      3      4      5      6      7      8
Temo :  3.95   0.00   3.56   3.55   3.49   3.28   3.19   3.52
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.12   2.36   2.16   2.75  -1.70  -13.6
 Thetab Htube      Ddo
  .859  1.279E+04  1.098E+04

Data Set Number = 26  Bulk Oil % =  0.0      2.11545545094
TC No:    1      2      3      4      5      6      7      8
Temp :  4.48   0.00   3.92   3.95   3.85   3.62   3.49   3.92
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.36   2.38   2.19   2.07  -1.67  -13.6
 Thetab Htube      Ddo
 1.073  1.411E+04  1.514E+04

Data Set Number = 27  Bulk Oil % =  0.0      2.11545545119
TC No:    1      2      3      4      5      6      7      8
Temp :  4.45   0.00   3.89   3.93   3.83   3.60   3.46   3.89
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.33   2.33   2.15   2.04  -1.72  -13.6
 Thetab Htube      Ddo
 1.092  1.385E+04  1.512E+04

Data Set Number = 28  Bulk Oil % =  0.0      2.11545545460
TC No:    1      2      3      4      5      6      7      8
Temp :  5.12   0.00   4.37   4.43   4.27   4.04   3.86   4.40
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.65   2.35   2.17   2.08  -1.70  -13.6
 Thetab Htube      Ddo
 1.390  1.437E+04  1.996E+04

Data Set Number = 29  Bulk Oil % =  0.0      2.11545545484
TC No:    1      2      3      4      5      6      7      8
Temp :  5.12   0.00   4.36   4.42   4.26   4.03   3.84   4.39
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 3.64   2.34   2.16   2.07  -1.71  -13.6
 Thetab Htube      Ddp
 1.393  1.433E+04  1.996E+04

Data Set Number = 30  Bulk Oil % =  0.0      2.11545546220
TC No:    1      2      3      4      5      6      7      8
Temp :  6.47   0.00   5.25   5.39   5.11   4.90   4.58   5.33
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsump
 4.23   2.31   2.18   2.10  -1.72  -13.6
 Thetab Htube      Ddp
 1.989  1.505E+04  2.993E+04

Data Set Number = 31  Bulk Oil % =  0.0      2.11545546248
TC No:    1      2      3      4      5      6      7      8
Temo :  6.45   0.00   5.23   5.37   5.09   4.88   4.57   5.31
 Twa    Tliod  Tliod2 Tvapr  Psat   Tsumo
 4.22   2.27   2.15   2.08  -1.75  -13.6
 Thetab Htube      Ddp
 2.003  1.497E+04  2.998E+04
```

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```
Data Set Number = 32  Bulk Oil % =  0.0    2.11545546659
TC No:    1      2      3      4      5      6      7      8
Temo :  8.99   0.00   6.66   6.92   6.39   6.17   5.57   6.63
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  5.16   2.33   2.18    2.13  -1.71  -13.4
  Thetab Htube      Odp
  2.910  1.559E+04  4.535E+04

Data Set Number = 33  Bulk Oil % =  0.0    2.11545546682
TC No:    1      2      3      4      5      6      7      8
Temp :  8.97   0.00   6.64   6.90   6.37   6.14   5.56   6.62
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  5.15   2.30   2.17    2.10  -1.73  -13.3
  Thetab Htube      Odo
  2.911  1.556E+04  4.531E+04

Data Set Number = 34  Bulk Oil % =  0.0    2.11545546951
TC No:    1      2      3      4      5      6      7      8
Temp : 12.55   0.00   8.98   9.39   8.54   8.06   6.96   8.56
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  6.53   2.29   2.16    2.15  -1.74  -13.2
  Thetab Htube      Odp
  4.305  1.632E+04  7.028E+04

Data Set Number = 35  Bulk Oil % =  0.0    2.11545546986
TC No:    1      2      3      4      5      6      7      8
Temp : 12.59   0.00   9.01   9.42   8.57   8.09   6.99   8.60
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  6.56   2.31   2.19    2.18  -1.71  -13.2
  Thetab Htube      Odp
  4.315  1.627E+04  7.019E+04

Data Set Number = 36  Bulk Oil % =  0.0    2.11545547257
TC No:    1      2      3      4      5      6      7      8
Temp : 16.06   0.00  11.35  11.79  10.57  10.04   8.26  10.43
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  7.84   2.23   2.15    2.14  -1.77  -12.9
  Thetab Htube      Odp
  5.649  1.694E+04  9.569E+04

Data Set Number = 37  Bulk Oil % =  0.0    2.11545547281
TC No:    1      2      3      4      5      6      7      8
Temp : 16.11   0.00  11.39  11.81  10.59  10.07   8.28  10.46
  Twa    Tliqd  Tliqd2  Tvapr  Psat   Tsump
  7.87   2.26   2.18    2.17  -1.75  -12.8
  Thetab Htube      Odo
  5.656  1.692E+04  9.572E+04
NOTE: 37 data runs were stored in file DATA07051S

NOTE: 37 X-Y pairs were stored in plot data file PLOT07051S
```

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APPENDIX D: SAMPLE CALCULATION

Data run number 9 (saturation temperature was 2.22 °C and heat flux was 20.14 kW/m^2) was chosen for the sample calculation.

A. TEST-SECTION DIMENSIONS

```
Do  =   0.01588 m
Di  =   0.01270 m
D1  =   0.01143 m
D2  =   0.01588 m
L   =   0.20320 m
Lu  =   0.07620 m
```

B. MEASURED PARAMETERS

```
V      =   112.08 volts
I      =     1.94 volts
T1     =    16.51 °C
T2     =    15.80 °C
T3     =    15.88 °C
T4     =    15.93 °C
T5         not read due to defective thermocouple
T6     =    15.94 °C
T7     =    15.63 °C
T8     =    16.16 °C
Tsat   =     2.22 °C
kc     =   344.00 (W/m·K)
```

C. OUTER WALL TEMPERATURE OF THE BOILING TUBE

```
p     =   π·Do = 3.1416 · 0.01588 = 0.0499 (m)
Ac    =   π(Do²-Di²)/4 = 3.1416 · [(0.01588)²-(0.0127)²]/4
Ac    =   7.14E-5 (m²)
Qh    =   VI = 112.08 · 1.94 = 217.44 (W)
Tavg  =   Σ Tn /n = 15.97 (°C)
Two   =   Tavg - Qh·[ ln(D2/D1) / (2·π·L·kc) ]
Two   =   15.97 - 217.44·
          [ln(15.88/11.43)/(2·3.1416·0.203·344)]
```

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```
Two     =   15.80 (˚C)
θ       =   Two - Tsat = 15.80 - 2.22 = 13.58 ˚C
```

D. PROPERTIES OF R-114 AT FILM TEMPERATURE

```
Tf  =   (Two+Tsat)/2 = (15.80+2.22)/2 = 9.01 ˚C
μ   =   exp[-4.4636 + (1011.47/Tf)] · 1E-3
μ   =   exp[-4.4636+(1011.47/9.01)]  ·  1E-3  =  4.16E-4
        (N·s/m²)
Tc  =   Critical Temperature (R) = 753.95 (R)
Tf  =   9.01 (˚C) = 507.89 (R)
j   =   1 - Tf(R)/Tc(R) = 1 - 507.89/753.95 = 0.33
ρ   =   581.77 + 984.15·j^(1/3) + 263.02·j + 279.99·j^(1/2) +
        17.94·j² (kg/m³)
ρ   =   1504.22 (kg/m³)
ν   =   μ/ρ = 4.16E-4/1504.22 = 2.77E-7
k   =   7.10E-2 - (2.61E-4 · Tf(˚C))
k   =   7.10E-2 - (2.61E-4 · 9.01) = 6.86E-2 (W/m·K)
Tf  =   9.01 (˚C) = 282.16 (K)
Cp  =   400 + (1.65 · Tf) + (1.51E-3 · Tf²) - (6.68E-7 ·
        Tf³)
Cp  =   970.43 (J/kg·K)
α   =   k/ρ·Cp = 6.86E-2/(1504.22·970.43) = 4.7E-8 (m²/s)
β   =   -(Δρ/ΔT)/ρ = 1.92E-3 (1/K)
Pr  =   ν/α = 5.88
```

E. HEAT-FLUX CALCULATION

Average natural-convection heat transfer coefficient at non-boiling ends:

$$h = \frac{k}{Do} \cdot \left\{ 0.60+0.387 \cdot \frac{\left(\frac{g \cdot \beta \cdot (Do^3) \cdot \theta \cdot Tanh(m \cdot Lu)}{v \cdot \alpha \cdot Lu \cdot m} \right)^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}} \right\}^2$$

$$m = [h \cdot p/(kc \cdot Ac)]^{1/2}$$

h = 235.4 (W/m²·K)

The value for h was computed iteratively. A value for h of 190 (W/m²·K) was assumed at start of iteration.

Heat-transfer rate through non-boiling ends:

```
m   =   21.87 (1/m)
Qf  =   (h·p·kc·Ac)^(1/2)·θ·Tanh(m·Lu) = 6.79 (W)
```

Heat flux through active boiling surface

Q = $Q_h - 2 \cdot Q_f$ = $217.44 - 2 \cdot 6.79$ = 203.85 (W)
A_b = $\pi \cdot D_o \cdot L$ = $3.1416 \cdot 0.015875 \cdot 0.2032$ = $1.01E-2$ (m^2)
q'' = Q/A_b = $203.85/1.02E-2$ = $20,108$ (W/m^2)
h = q/θ = $20,108/13.59$ = 1480 $(W/m^2 \cdot K)$

The following are the results obtained from the computer
by running the data reduction program DRP8 (See Appendix H).

q'' = $20,140$ (W/m^2)
θ = 13.64 $(°C)$
h = 1477 $(W/m^2 \cdot K)$

TABLE IV. DIMENSIONS OF BOILING TUBES

	D1 (mm)	D2 (mm)	Di (mm)	Do (mm)	L (mm)	Lu (mm)	Kcu $\frac{(W)}{m^2 \cdot K}$
Smooth	12.44	15.88	12.70	15.88	203.2	76.20	344
GEWA-K 26 fpi	10.1	12.7	11.11	12.7	203.2	76.2	398
GEWA-K 40 fpi	10.1	12.7	11.11	12.7	203.2	76.2	398
GEWA-T 19 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
GEWA-T 26 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
GEWA-YX 26 fpi	11.57	13.8	11.8	13.31	203.2	76.2	398
Thermoexcel-E	11.57	13.8	11.8	13.31	203.2	76.2	398
Thermoexcel-HE	11.57	13.8	11.8	13.31	203.2	76.2	398
Turbo-B	11.57	13.8	11.8	15.8	203.2	76.2	398
High Flux (Copper/ Nickel 95/5)	12.95	15.82	13.2	15.82	203.2	76.2	45

APPENDIX E: UNCERTAINTY ANALYSES

Four data points from two data runs were chosen for the uncertainty analysis: data run number 8 (smooth tube, 0% oil, 100,000 & 3500 W/m²) and data run number 74 (Thermoexcel-E, 0% oil, 6000 & 100,000 W/m². The dimensions of the boiling tubes can be found in Appendix D, Table IV. The measured and calculated parameters used in this analysis were obtained as shown in Appendix D and are listed in Table V of this appendix. All uncertainties are presented as a percentage of the calculated parameter. What follows is a sample calculation for data run number 8: smooth tube, 0% oil at a heat flux of 93,130 W/m² using the methods outlined by Kline and McClintock [Ref. 17]. All other data point uncertainties were calculated similarly, the results of which are listed in Table V of this appendix.

A. UNCERTAINTY IN SOURCE HEAT-TRANSFER RATE

```
Qh  =   VI W
Is  =   2.122 volts        δI  = ± 0.025 amp
Vs  =   9.45 volts         δV  = ± 0.05 volts
I   =   1.9182·Is = 4.07 amp
V   =   25·Vs = 236.26 volts
```

where:

δ = uncertainty in measurement and calculation

$$\delta Qh/Qh = ((\delta V/Vs)^2 + (\delta I/Is)^2)^{1/2}$$
$$\delta Qh/Qh = ((0.05/9.45)^2 + (0.025/2.122)^2)^{1.2}$$
$$\delta Qh/Qh = 1.29 \text{ percent}$$

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B. UNCERTAINTY IN SURFACE AREA

Ab = $\pi \cdot Do \cdot L$
Do = 15.88 (mm) δDo = 0.1 (mm)
L = 203.20 (mm) δL = 0.1 (mm)

$\delta Ab/Ab$ = $((\delta Do/Do)^2 + (\delta L/L)^2)^{1/2}$
$\delta Ab/Ab$ = $((0.1/15.88)^2 + (0.1/203.2)^2)^{1/2}$
$\delta Ab/Ab$ = 0.63 percent

C. UNCERTAINTY IN WALL SUPERHEAT

ΔT = $Two - Tsat$

$Tsat$ = 2.22 °C δT = 0.01 °C

Two = $Tavg - Qh[(\ln(D2/D1))/(2 \cdot \pi \cdot L \cdot kc)]$
$Tavg$ = $(\sum Tn/8)$ where n = 1 to 8
Tn = thermocouple readings
$T1$ = 23.86 °C $T2$ = 19.62 °C $T3$ = 20.38 °C
$T4$ = 19.87 °C $T5$ = Defective thermocouple
$T6$ = 20.18 °C $T7$ = 20.16 °C $T8$ = 20.20 °C
$Tavg$ = 20.18 °C

$S.D.$ = $((\sum(Tn - Tavg)^2)/7)^{1/2}$ = 0.19 °C
          where S.D. = standard deviation

The logarithmic term in equation of Two is very small compared to the standard deviation, this term can be neglected for the uncertainty analysis.

Two = $Tavg$ = 18.72 °C δTwo = S.D. = 0.19 °C

ΔT = 17.96 °C

$\delta \Delta T/\Delta T$ = $((\delta Two/\Delta T)^2 + (-\delta Tsat/\Delta T)^2)^{1/2}$
$\delta \Delta T/\Delta T$ = $((0.93/16.5)^2 + (0.01/16.5)^2)^{1/2}$
$\delta \Delta T/\Delta T$ = 1.06 percent

D. UNCERTAINTY IN HEAT FLUX

q = $(Qh-2Qf)/Ab$

Qh = 961.58 W δQh = 12.42 W

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Assuming the same proportion in the uncertainty for Qf:

Qf =   8.99 W   δQf =   0.12 W

Qh - 2Qf   =   943.6 W

$\delta q/q$ = $[(\delta Qh/(Qh-2Qf))^2$ + $(2\delta Qf/(Qh-2Qf))^2)$ +
            $(\delta Ab/Ab)^2)]^{1/2}$
$\delta q/q$ = $[(12.42/943.6)^2 + (0.24/943.6)^2 + (0.0063)^2]^{1/2}$
$\delta q/q$ =   1.46 percent

E.   UNCERTAINTY IN BOILING HEAT-TRANSFER COEFFICIENT

    h   = $q/\Delta T$

$\delta h/h$ = $[(\delta q/q)^2 + (\delta \Delta T/\Delta T)^2]^{1/2}$
$\delta h/h$ = $[(0.0146)^2 + (0.01.06)^2]^{1/2}$
$\delta h/h$ =   1.8 percent

TABLE V. UNCERTAINTY ANALYSIS OF FOUR DATA POINTS

PARAMETERS	SMOOTH 100 kW/m²	SMOOTH 3500 W/m²	THERMO-E 6000 W/m²	THERMO-E 100 kW/m²
Is (amp)	2.122	0.454	0.494	2.06
Vs (volts)	0.05	2.09	2.20	8.88
I (amp)	4.07	0.90	0.98	3.95
δI (amp)	0.025	0.025	0.025	0.025
V (volts)	236.26	52.29	55.28	222.05
δV (volts)	0.05	0.05	0.05	0.05
Qh (W)	961.58	47.06	54.17	877.1
δQh (W)	12.42	2.83	3.00	7.43
δQh/Qh (%)	1.29	6.00	5.55	0.85
Do (mm)	15.88	15.88	13.31	13.31
δDo (mm)	0.1	0.1	0.1	0.1
L (mm)	203.2	203.2	203.2	203.2
δL (mm)	0.1	0.1	0.1	0.1
Ab (m²)	1.014E-2	1.014E-2	8.50E-3	8.50E-3
δAb/Ab (%)	0.63	0.63	0.75	0.75
δTsat (°C)	0.01	6.00	0.01	2.91
Two (°C)	20.18	12.92	2.77	11.13
δTwo (°C)	0.19	0.28	8.53E-2	0.36
ΔT (°C)	17.96	10.70	0.53	9.80
$\delta\Delta$T/ΔT (%)	1.06	2.62	16.20	3.67
Qf (W)	8.99	5.02	5.69	2.91
δQf	0.12	0.03	0.15	2.48E-2
Qh-2Qf (W)	943.60	37.02	54.06	871.3
q (W/m²)	93,081	3664	6109	102,542
δq/q (%)	1.46	7.67	5.63	1.14
h (W/m²•K)	5182	342.4	11,200	10,463
δh/h (%)	1.80	8.10	17.15	3.84
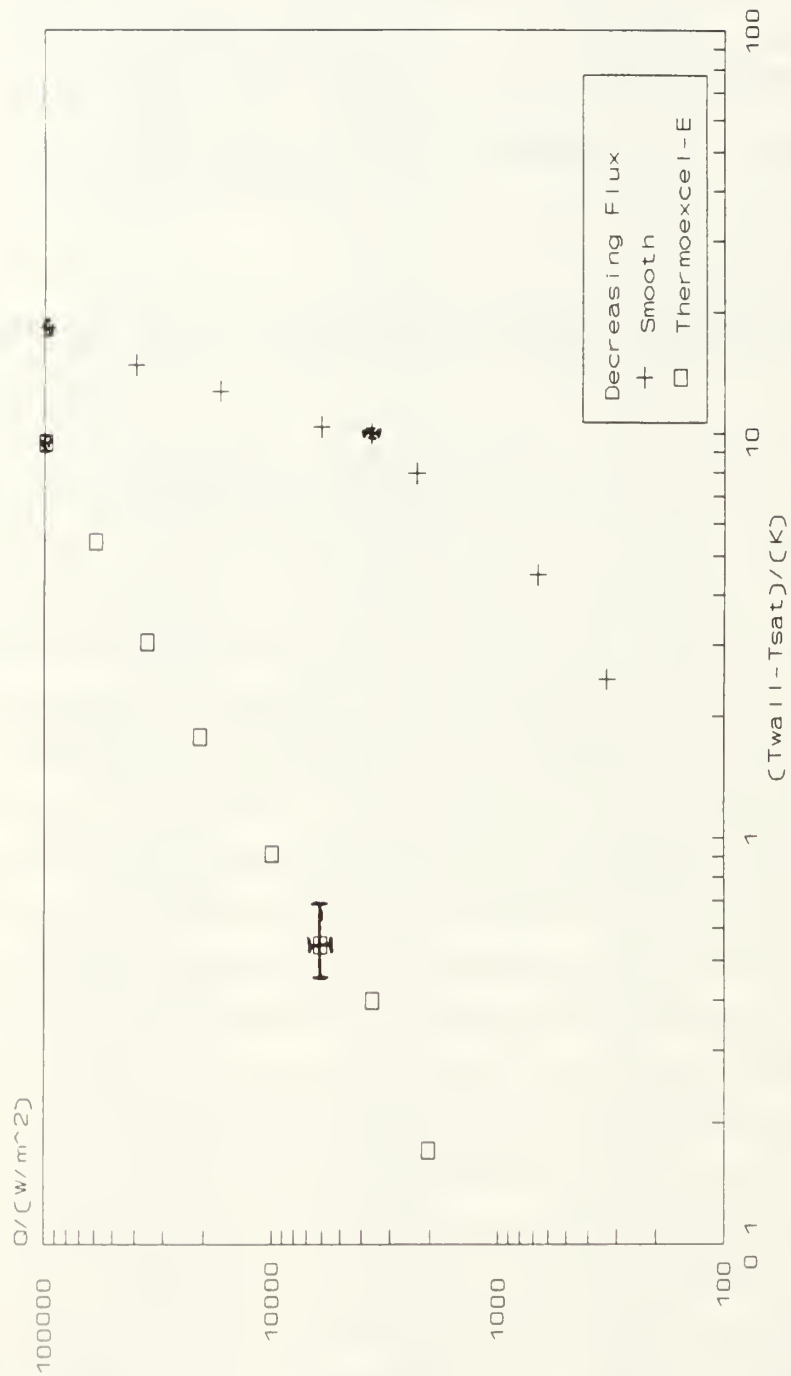
Figure E.1 Uncertainty Analysis
Error Bands for Heat Flux and Superheat

APPENDIX F: SETUP PROGRAM

The following is a listing of the complete setup program used in the preparation of the apparatus for testing. It consists of five sections:

1. Monitor the Sump temperature

2. Monitor the evaporator liquid temperature

3. Measurement and readout of all thermocouple channels.

4. Measurement and readout of the power supplied to the tube cartridge heater.

5. Measurement and readout of the power supplied to the auxilliary heaters if used.

The program was written in Hewlett-Packard Basic 5.0 for both the Hewlett-Packard 9300 series computer and 9852A series data acquisition/control unit.

```
1  1   PROGRAM: SETUP PROGRAM FOR HP 3852A
2  1   DATE:   AUGUST 13,1991
3  1   PROGRAMMER: LT DEAN SUGIYAMA
13     REAL T(0:12),Sum(0:12),Temp(0:12),E(1:3)
23     ON KEY 0,15 GOTO 27
25     PRINTER IS 1
27     PRINT
28     PRINT
30     PRINT USING "4X,""SELECT OPTION"""
31     PRINT USING "6X,""0-MONITOR SUMP"""
32     PRINT USING "6X,""1-MONITOR LIQUID"""
33     PRINT USING "6X,""2-CHECK THERMOCOUPLES"""
34     PRINT USING "6X,""3-CHECK MAIN HEATER"""
35     PRINT USING "6X,""4-CHECK AUX HEATERS"""
36     PRINT USING "6X,""5-EXIT PROGRAM"""
37     PRINT USING "4X,""NOTE: KEY 0 = ESCAPE"""
38     BEEP
40     INPUT Ido
41     IF Ido>5 THEN Ido=5
42     IF Ido=0 THEN 50
43     IF Ido=1 THEN 155
44     IF Ido=2 THEN 185
45     IF Ido=3 THEN 209
46     IF Ido=4 THEN 209
47     IF Ido=5 THEN 252
48     PRINT
491
50     PRINT
51     PRINT "SUMP TEMPERATURE DEG C "
53     PRINT
54     OUTPUT 709;"RST"
55     Tot=0
56     FOR J=1 TO 5
60     OUTPUT 709;"CONFMEAS TEMPT,511,USE 600"
90     ENTER 709;A
100    Tot=Tot+A
110    NEXT J
120    Tavg=Tot/5
140    PRINT USING "4X,MDO.DO";Tavg
141    BEEP
142    PRINT
150    WAIT 60
151    GOTO 50
1521
155    PRINT
156    PRINT "LIQUID TEMPERATURE DEG C"
158    PRINT
159    OUTPUT 709;"RST"
160    FOR I=1 TO 2
162    Sum(I)=0
163    T(I)=0
165    NEXT I
166    FOR J=1 TO 5
167    OUTPUT 709;"CONFMEAS TEMPT,508-509,USE 600"
168    FOR I=1 TO 2
169    ENTER 709;T(I)
170    Sum(I)=Sum(I)+T(I)
171    NEXT I
172    NEXT J
173    FOR I=1 TO 2
```

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```
174    Temp(I)=Sum(I)/5
175    NEXT I
176    Tavg=(Temp(1)+Temp(2))/2
180    PRINT USING "4X,MDD.DD";Tavg
181    BEEP
182    WAIT 60
183    GOTO 155
184!
185    PRINT
186    PRINT "CHANNEL        TEMPERATURE DEG C"
187    OUTPUT 709;"RST"
188    FOR I=1 TO 12
189    Sum(I)=0
190    T(I)=0
192    NEXT I
193    FOR J=1 TO 5
194    OUTPUT 709;"CONFMEAS TEMPT,500-511,USE 600"
195    FOR I=1 TO 12
196    ENTER 709;T(I)
197    Sum(I)=Sum(I)+T(I)
198    NEXT I
200    NEXT J
201    FOR I=1 TO 12
202    Temp(I)=Sum(I)/5
203    PRINT TAB(3);I;TAB(15);Temp(I)
204    NEXT I
205    BEEP
206    WAIT 5
207    GOTO 185
208!
209    PRINT
210    OUTPUT 709;"RST"
211    FOR I=1 TO 3
212    Sum(I)=0
215    NEXT I
216    FOR J=1 TO 5
218    OUTPUT 709;"CONFMEAS DCV,512-514,USE 600"
219    FOR I=1 TO 3
221    ENTER 709;E(I)
222    Sum(I)=Sum(I)+E(I)
223    NEXT I
225    NEXT J
226    Amp=0
228    FOR I=1 TO 3
229    IF I=1 THEN Volt=Sum(I)/5
230    IF I=2 AND Ido=3 THEN
231    PRINT "MAKE SURE VOLTAGE BOX IS SET TO MAIN HEATERS"
232    Amp=Sum(I)/5
233    END IF
234    IF I=3 AND Ido=4 THEN
235    PRINT "MAKE SURE VOLTAGE BOX IS SET TO AUX HEATERS"
236    Amp=Sum(I)/5
237    END IF
238    NEXT I
239    Amp=ABS(Amp*1.9182)
240    Volt=ABS(Volt*25)
241    Power=Volt*Amp
242    Resistence=Volt/Amp
243    IF Amp=0 THEN Resistence=0
245    PRINT
```

```
246    BEEP
247    PRINT "    VOLTAGE(V)    CURRENT(A)    RESISTENCE(ohms)    POWER(W)"
248    PRINT
249    PRINT USING "1X,5(MDDDDDD.DDD,3X)";Volt,Amp,Resistence,Power
250    WAIT 5
251    GOTO 209
252    BEEP
253    PRINT
254    PRINT
255    END
```

APPENDIX G: DATA REDUCTION PROGRAM

The following is a listing of the complete data-reduction program, DRP8, written in Hewlett-Packard Basic 5.0 for both the Hewlett-Packard 9300 series computer and 9852A series data acquisition/control unit.

```
1000! FILE NAME: DRP8
1004! DATE:       October 19, 1984
1008! REVISED:    August 14,1991 by LT Dean Sugiyama
1012!
1016  COM /Idp/ Idp
1020  PRINTER IS 1
1024  CALL Select
1028  INPUT "WANT TO SELECT ANOTHER OPTION (1=Y,0=N)?",Isel
1032  IF Isel=1 THEN GOTO 1024
1036  BEEP
1040  BEEP
1044  PRINTER IS 1
1048  PRINT "DATA COLLECTION/REPROCESSING COMPLETED"
1052  END
1056  SUB Main
1060  COM /Idp/ Idp
1064  COM /Cc/ C(7),Ical
1068  COM /Wil/ D2,D1,Do,L,Lu,Kcu
1072  DIM Emf(12),T(12),D1a(13),D2a(13),Dia(13),Doa(13),La(13),Lua(13),Kcua(13),
Et1(20),Et2(20),Tn$(4)[15],Sum(20),Tt(12),Ta(12),Vt(2),Va(2),Eliq(12),E(12)
1076  DATA 0.10086091,25727.94369,-767345.8295,78025595.81
1080  DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
1084  READ C(*)
1088! DATA "Smooth","High Flux","Thermoexel-E","Thermoexel-HE"
1092  DATA Smooth,High Flux,Turbo-B,High Flux Mod,Turbo-B Mod
1096  READ Tn$(*)
1100  PRINTER IS 701
1104  BEEP
1108  IF Idp=4 THEN PRINTER IS 1
1112  IF Idp=4 THEN GOTO 2032
1116  OUTPUT 709;"RST"
1120  OUTPUT 709;"SET TIMEDATE";TIMEDATE
1124  OUTPUT 709;"TIMEDATE"
1128  ENTER 709;Dt
1132  PRINT
1136  PRINT "           Month, date and time :";DATE$(Dt),TIME$(Dt)
1140  PRINT
1144  PRINT USING "10X,""NOTE: Program name : DRP8"""
1148  BEEP
1152  INPUT "ENTER DISK NUMBER",Dn
1156  PRINT USING "16X,""Disk number  = "",ZZ";Dn
1160  BEEP
1164  INPUT "ENTER INPUT MODE (0=3852A,1=FILE)",Im
1168  BEEP
1172  INPUT "SELECT HEATING MODE (0=ELEC; 1=WATER)",Ihm
1176  BEEP
1180  INPUT "ENTER THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
1184  IF Im=0 THEN
1188  BEEP
1192  INPUT "GIVE A NAME FOR THE RAW DATA FILE",D2_file$
1196  PRINT USING "16X,""New file name: "",14A";D2_file$
1200  Size1=20
1204  CREATE BDAT D2_file$,Size1
1208  ASSIGN @File2 TO D2_file$
1212!
1216! DUMMY FILE UNTIL Nrun KNOWN
1220  D1_file$="DUMMY"
1224  CREATE BDAT D1_file$,Size1
1228  ASSIGN @File1 TO D1_file$
```

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```
1232   OUTPUT @File1;Dt
1236   IF Ihm=0 THEN
1240   BEEP
1244   INPUT "ENTER NUMBER OF DEFECTIVE TCS (0=DEFAULT)",Idtc
1248   IF Idtc=0 THEN
1252   Ldtc1=0
1256   Ldtc2=0
1260   PRINT USING "16X,""No defective TCs exist"""
1264   END IF
1268   IF Idtc=1 THEN
1272   BEEP
1276   INPUT "ENTER DEFECTIVE TC LOCATION",Ldtc1
1280   PRINT USING "16X,""TC is defective at location "",DD";Ldtc1
1284   Ldtc2=0
1288   END IF
1292   IF Idtc=2 THEN
1296   BEEP
1300   INPUT "ENTER DEFECTIVE TC LOCATIONS",Ldtc1,Ldtc2
1304   PRINT USING "16X,""TC are defective at locations "",DD,4X,DD";Ldtc1,Ldtc2
1308   END IF
1312   IF Idtc>2 THEN
1316   BEEP
1320   PRINTER IS 1
1324   BEEP
1328   PRINT "INVALID ENTRY"
1332   PRINTER IS 701
1336   GOTO 1240
1340   END IF
1344   END IF
1348   OUTPUT @File1;Ldtc1,Ldtc2
1352!  Im=1 option
1356   ELSE
1360   BEEP
1364   INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D2_file$
1368   PRINT USING "16X,""Old file name: "",14A";D2_file$
1372   ASSIGN @File2 TO D2_file$
1376   ENTER @File2;Nrun
1380   ENTER @File2;Dt
1384   PRINT USING "16X,""This data set taken on : "",11A";DATE$(Dt)
1388   ENTER @File2;Ldtc1,Ldtc2
1392   IF Ldtc1>0 OR Ldtc2>0 THEN
1396   PRINT USING "16X,""Thermocouples were defective at locations:"",2(3D,4X)";
Ldtc1,Ldtc2
1400   END IF
1404   ENTER @File2;Itt
1408   END IF
1409   Idtc=0
1411   IF Ldtc1>0 THEN Idtc=Idtc+1
1412   IF Ldtc2>0 THEN Idtc=Idtc+1
1413!  IF Im=0 AND Ihm=1 THEN 1595
1416   BEEP
1420   INPUT "WANT TO CREATE A PLOT FILE? (0=N,1=Y)",Iplot
1424   IF Iplot=1 THEN
1428   BEEP
1432   INPUT "GIVE NAME FOR PLOT FILE",P_file$
1436   CREATE BDAT P_file$,4
1440   ASSIGN @Plot TO P_file$
1444   END IF
1448   IF Ihm=1 THEN
1452   BEEP
```

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```
1456  INPUT "WANT TO CREATE Uo FILE? (0=N,1=Y)",Iuf
1460  IF Iuf=1 THEN
1464  BEEP
1468  INPUT "ENTER Uo FILE NAME",Ufile$
1472  CREATE BDAT Ufile$,4
1476  ASSIGN @Ufile TO Ufile$
1480  END IF
1484  BEEP
1488  INPUT "WANT TO CREATE Re FILE? (0=N,1=Y)",Ire
1492  IF Ire=1 THEN
1496  BEEP
1500  INPUT "ENTER Re FILE NAME",Refile$
1504  CREATE BDAT Refile$,10
1508  ASSIGN @Refile TO Refile$
1512  END IF
1516  END IF
1520  PRINTER IS 1
1524  IF Im=0 THEN
1528  BEEP
1532  PRINT USING "4X,""Select tube number"""
1536  IF Ihm=0 THEN
1540  PRINT USING "6X,""0  Smooth 4 inch Ref"""
1544  PRINT USING "6X,""1  Smooth 4 inch Cu (Press/Slide)"""
1548  PRINT USING "6X,""2  Soft Solder 4 inch Cu"""
1552  PRINT USING "6X,""3  Soft Solder 4 inch HIGH FLUX"""
1556  PRINT USING "6X,""4  Wieland Hard 8 inch"""
1560  PRINT USING "6X,""5  HIGH FLUX 8 inch"""
1564  PRINT USING "6X,""6  GEWA-K 40 Fins/in"""
1568  PRINT USING "6X,""7  GEWA-K 26 Fins/in"""
1572  PRINT USING "6X,""8  GEWA-T 19 Fins/in"""
1576  PRINT USING "6X,""9  GEWA-T OR GEWA-TY 26 Fins/in"""
1580  PRINT USING "6X,""10  THERMOEXCEL-E"""
1584  PRINT USING "6X,""11  THERMOEXCEL-HE"""
1585  PRINT USING "6X,""12  TURBO-B"""
1586  PRINT USING "6X,""13  GEWA-K 19 Fins/in"""
1588  ELSE
1592  PRINT USING "6X,""0  Smooth tube"""
1596  PRINT USING "6X,""1  High Flux"""
1600  PRINT USING "6X,""2  Turbo-B"""
1604  PRINT USING "6X,""3  High Flux Mod"""
1608  PRINT USING "6X,""4  Turbo-B Mod"""
1612  END IF
1616  INPUT Itt
1620  OUTPUT @File1;Itt
1624  END IF
1628  PRINTER IS 701
1632  IF Itt<10 THEN PRINT USING "16X,""Tube Number:    "",D";Itt
1636  IF Itt>9 THEN PRINT USING "16X,""Tube Number:    "",DD";Itt
1640  IF Ihm=1 THEN PRINT USING "16X,""Tube Type:      "",15A";Tn$(Itt)
1644  BEEP
1648  INPUT "ENTER OUTPUT VERSION (0=LONG,1=SHORT,2=NONE)",Iov
1652  BEEP
1656  INPUT "SELECT (0=LIQ,1=VAP,2=(LIQ+VAP)/2)",Ilqv
1660!
1664! DIMENSIONS FO TESTED TUBES
1668! ELECTRIC HEATED MODE
1672! D1=Diameter at thermocouple positions
1676  DATA .0111125,.0111125,.0111125,.0129540,.012446,.0129540,.0100965
1680  DATA .0100965,.01157,.01157,.01157,.01157,.01157,.0100965
1684  READ Dia(*)
```

```
1688    D1=Dia(Itt)
1692!
1696!   D2=Diameter of test section to the base of fins
1700    DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270
1704    DATA .0127,.0138,.0138,.0138,.0138,.0138,.0127
1708    READ D2a(•)
1712!
1716!   Di=Inside diameter of unenhanced ends
1720    DATA .0127,.0127,.0127,.0132,.0127,.0132,.0111125,.0111125
1721    DATA .0118,.0118,.0118,.0118,.0118,.0111125
1724    READ Dia(•)
1728!
1732!   Do=Outside diameter of unenhanced ends
1736    DATA .015875,.015875,.015875,.015824,.015875,.015824,.01270,.01270
1737    DATA .01331,.01331,.01331,.01331,.0158,.0127
1740    READ Doa(•)
1744!
1748!   L=Length of enhanced surface
1752    DATA .1016,.1016,.1016,.1016,.2032,.2032,.2032,.2032,.2032,.2032,.2032,.20
32,.2032,.2032
1756    READ La(•)
1760!
1764!   Lu=Length of unenhanced surface at the ends
1768    DATA .0254,.0254,.0254,.0254,.0762,.0762,.0762,.0762,.0762,.0762,.0762,.07
62,.0762,.0762
1772    READ Lua(•)
1776!
1780!   Kcu=Thermal Conductivity of tube
1784    DATA 398,344,344,45,344,45,344,344,398,398,398,398,398,344
1788    READ Kcua(•)
1792    IF Ihm=1 THEN
1796!
1800!   Data statements for water heating mode
1804!
1808    DATA 0.015875,0.015875,0.0169,0.0138,0.0169,0,0,0,0,0
1812    READ D2a(•)
1816    DATA 0.0127,0.0127,0.0145,0.0127,0.0145,0,0,0,0,0
1820    READ Dia(•)
1824    DATA 0.015875,0.015875,0.0169,0.015875,0.0169,0,0,0,0,0
1828    READ Doa(•)
1832    DATA 0.3048,0.3048,0.3048,0.3048,0.3048,0,0,0,0,0
1836    READ La(•)
1840    DATA 0.0254,0.0254,0.0254,0.0254,0.0254,0,0,0,0,0
1844    READ Lua(•)
1848    DATA 398,45,398,45,398,0,0,0,0,0
1852    READ Kcua(•)
1856    END IF
1860    D2=D2a(Itt)
1864    Di=Dia(Itt)
1868    Do=Doa(Itt)
1872    L=La(Itt)
1876    Lu=Lua(Itt)
1880    Kcu=Kcua(Itt)
1884    Xn=.8
1888    Fr=.3
1892    IF Itt=0 THEN Cf=1.70E+9
1896    IF Itt>0 THEN Cf=3.7037E+10
1900    A=PI•(Do^2-Di^2)/4
1904    P=PI•Do
1908    IF Ihm=1 THEN
```

```
1912  BEEP
1916  INPUT "TUBE INITIATION MODE. (1-HOT WATER,2-STEAM,3-COLD WATER)",Itim
1920  IF Itim=1 THEN PRINT USING "16X,""Tube Initiate: Hot Water"""
1924  IF Itim=2 THEN PRINT USING "16X,""Tube Initiate: Steam"""
1928  IF Itim=3 THEN PRINT USING "16X,""Tube Initiate: Cold Water"""
1932  INPUT "TEMP/VEL MODE: (0-T-CONST,V-DEC;1-T-DEC,V-CONST; 2-T-INC,V-CONST)",
Itv
1936  IF Itv=0 THEN PRINT USING "16X,""Temp/Vel Mode: Constant/Decreasing"""
1940  IF Itv=1 THEN PRINT USING "16X,""Temp/Vel Mode: Decreasing/Constant"""
1944  IF Itv=2 THEN PRINT USING "16X,""Temp/Vel Mode: Increasing/Constant"""
1948  INPUT "WANT TO RUN WILSON PLOT? (1-Y,0-N)",Iwil
1952  IF Ihm=1 AND Iwil=0 THEN
1956  IF Itt=0 THEN Ci=.032
1960  IF Itt=1 OR Itt=3 THEN Ci=.059
1964  IF Itt=2 OR Itt=4 THEN Ci=.062
1968  BEEP
1972  INPUT "ENTER CI (DEF: WH=.032,HF=.059,TB=.062)",Ci
1976  PRINT USING "16X,""Sieder-Tate """
1980  PRINT USING "16X,""  Constant   = "",Z.4D";Ci
1984  END IF
1988  END IF
1992  IF Ihm=1 AND Im=1 AND Iwil=1 THEN
1996  IF Itt=0 THEN Ci=.032
2000  IF Itt=1 OR Itt=3 THEN Ci=.059
2004  IF Itt=2 OR Itt=4 THEN Ci=.062
2008  ASSIGN @File2 TO *
2012  CALL Wilson(Cf,Ci)
2016  ASSIGN @File2 TO D2_file$
2020  ENTER @File2;Nrun,Dold$,Ldtc1,Ldtc2,Itt
2024  END IF
2028  Nsub=0
2032  IF Idp=4 THEN Ihm=1
2036  IF Ihm=1 THEN Nsub=8
2040  Ntc=6
2041  IF Ihm=0 THEN Ntc=12
2044  J=1
2048  Sx=0
2052  Sy=0
2056  Sxs=0
2060  Sxy=0
2064 Repeat: !
2068  IF Im=0 THEN
2072  Dtld=2.22
2076  Ido=2
2080  ON KEY 0,15 RECOVER 2064
2084  PRINTER IS 1
2088  PRINT USING "4X,""SELECT OPTION"""
2092  PRINT USING "6X,""0-TAKE DATA"""
2096  IF Ihm=0 THEN PRINT USING "6X,""1-SET HEAT FLUX"""
2100  IF Ihm=1 THEN PRINT USING "6X,""1-SET WATER FLOW RATE"""
2104  PRINT USING "6X,""2-SET Tsat"""
2108  PRINT USING "4X,""NOTE: KEY 0 = ESCAPE"""
2112  BEEP
2116  INPUT Ido
2120  IF Ido>2 THEN Ido=2
2124  IF Ido=0 THEN 2724
2128!
2132! LOOP TO SET HEAT FLUX OR FLOWMETER SETTING
2136  IF Ido=1 THEN
2140  IF Ihm=0 THEN
```

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```
2148  BEEP
2152  INPUT "ENTER DESIRED Qdp",Dqdp
2156  PRINT USING "4X,""DESIRED Qdp   ACTUAL Qdp"""
2160  Err=1000
2164  FOR I=1 TO 2
2165  Sum(I)=0
2166  Vt(I)=0
2168  NEXT I
2169  OUTPUT 709;"RST"
2176  FOR J1=1 TO 5
2180  OUTPUT 709;"CONFMEAS DCV,512-513,USE 600"
2181  FOR I=1 TO 2
2182  ENTER 709;Vt(I)
2184  Sum(I)=Sum(I)+Vt(I)
2185  NEXT I
2188  NEXT J1
2189  FOR I=1 TO 2
2192  IF I=1 THEN Volt=Sum(I)/5
2196  IF I=2 THEN Amp=Sum(I)/5
2200  NEXT I
2201  Amp=ABS(Amp*1.9182)
2202  Volt=ABS(Volt*25)
2204  Aqdp=Volt*Amp/(PI*D2*L)
2208  IF ABS(Aqdp-Dqdp)>Err THEN
2212  IF Aqdp>Dqdp THEN
2216  BEEP 4000,.2
2220  BEEP 4000,.2
2224  BEEP 4000,.2
2228  ELSE
2232  BEEP 250,.2
2236  BEEP 250,.2
2240  BEEP 250,.2
2244  END IF
2248  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
2252  WAIT 2
2256  GOTO 2164
2260  ELSE
2264  BEEP
2268  PRINT USING "4X,MZ.3DE,2X,MZ.3DE";Dqdp,Aqdp
2272  Err=500
2276  WAIT 2
2280  GOTO 2164
2284  END IF
2288  ELSE
2292  BEEP
2296  INPUT "ENTER FLOWMETER SETTING",Fms
2300  GOTO 2088
2304  END IF
2308  END IF
2312 !
2316 ! LOOP TO SET Tsat
2320  IF Ido=2 THEN
2324  IF Ikdt=1 THEN 2344
2328  BEEP
2332  INPUT "ENTER DESIRED Tsat",Dtld
2336 ! PRINT USING "4X,"" DTsat  ATsat   Rate    Tv     Rate"""
2340  Ikdt=1
2344  Old1=0
2348  Old2=0
2352  Nn=1
```

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```
2356  Nrs=Nn MOD 15
2360  Nn=Nn+1
2364  IF Nrs=1 THEN
2365  IF Ihm=0 THEN PRINT USING "4X,""   Tsat     Tld1     TldZ     Tv      Tsum
p"""
2368  IF Ihm=1 THEN PRINT USING "4X,""   Tsat     Tld1     Tld2     Tv     Tsump   Tinle
t   Tpile   Tout"""
2372  END IF
2373  FOR I=1 TO 6
2374  Sum(I)=0
2375  NEXT I
2376  OUTPUT 709;"RST"
2377  FOR Ji=1 TO 20
2379  IF Ihm=0 THEN OUTPUT 709;"CONFMEAS TEMPT,508-511,USE 600"
2380  IF Ihm=1 THEN OUTPUT 709;"CONFMEAS TEMPT,300-305,USE 600"
2384  FOR I=1 TO 6
2388  IF Ihm=0 AND I>4 THEN 2401
2392  ENTER 709;Eliq(I)
2396  Sum(I)=Sum(I)+Eliq(I)
2400  NEXT I
2401  NEXT Ji
2402  FOR I=1 TO 6
2403  IF Ihm=0 AND I>4 THEN 2496
2416  Eliq(I)=Sum(I)/20
2424  IF I=1 THEN Tld1=Eliq(I)
2428  IF I=2 THEN Tld2=Eliq(I)
2432  IF I=3 THEN Tv=Eliq(I)
2436  IF I=4 THEN Tsump=Eliq(I)
2440  IF I=5 THEN Tinlet=Eliq(I)
2444  IF I=6 THEN Tout=Eliq(I)
2448  NEXT I
2452  IF Ihm=1 THEN
2456  Sum1=0
2460  OUTPUT 709;"RST"
2468  FOR Kk=1 TO 20
2469  OUTPUT 709;"CONFMEAS TEMPT,320,USE 600"
2472  ENTER 709;E1
2476  Sum1=Sum1+E1
2480  NEXT Kk
2484  Emf(7)=ABS(Sum1/20)
2488  Tpile=Emf(7)/3.96E-4
2492  END IF
2496  Atld=(Tld1+Tld2)*.5
2500  IF ABS(Atld-Dtld)>.2 THEN
2504  IF Atld>Dtld THEN
2508  BEEP 4000,.2
2512  BEEP 4000,.2
2516  BEEP 4000,.2
2520  ELSE
2524  BEEP 250,.2
2528  BEEP 250,.2
2532  BEEP 250,.2
2536  END IF
2540  Err1=Atld-Old1
2544  Old1=Atld
2548  Err2=Tv-Old2
2552  Old2=Tv
2553  IF Tld1>100. THEN 2572
2556  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Tsump
2560  IF Ihm=1 AND Idp=0 THEN PRINT USING "4X,7(MDD.DD,2X)";Dtld,Tld1,Tld2,Tv,Ts
```

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```
ump.Tinlet.Tpile
2564  IF Ihm=1 AND Idp=4 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,2X)";Dtld.Tl
dl.Tld2.Tv,Tsump.Tinlet.Tpile.Tout
2568  WAIT 2
2572  GOTO 2356
2576  ELSE
2580  IF ABS(Atld-Dtld)>.1 THEN
2584  IF Atld>Dtld THEN
2588  BEEP 3000,.2
2592  BEEP 3000,.2
2596  ELSE
2600  BEEP 800,.2
2604  BEEP 800,.2
2608  END IF
2612  Err1=Atld-Old1
2616  Old1=Atld
2620  Err2=Tv-Old2
2624  Old2=Tv
2628  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld.Tld1.Tld2.Tv.Tsump
2632  IF Ihm=1 THEN PRINT USING "4X,5(MDD.DD,2X),3(M3D.DD,1X)";Dtld.Tld1.Tld2.Tv
,Tsump.Tinlet.Tpile.Tout
2636  WAIT 2
2640  GOTO 2356
2644  ELSE
2648  BEEP
2652  Err1=Atld-Old1
2656  Old1=Atld
2660  Err2=Tv-Old2
2664  Old2=Tv
2668  IF Ihm=0 THEN PRINT USING "4X,5(MDDD.DD,2X)";Dtld.Tld1.Tld2.Tv.Tsump
2672  IF Ihm=1 THEN PRINT USING "4X,8(MDD.DD,2X)";Dtld.Tld1.Tld2.Tv.Tsump.Tinlet
,Tpile.Tout
2676  WAIT 2
2680  GOTO 2356
2684  END IF
2688  END IF
2692  END IF
2696! ERROR TRAP FOR Ido OUT OF BOUNDS
2700  IF Ido>2 THEN
2704  BEEP
2708  GOTO 2088
2712  END IF
2716!
2720! TAKE DATA IF Im=0 LOOP
2724  IF Ikol=1 THEN 2737
2728  BEEP
2732  INPUT "ENTER BULK OIL %",Bop
2736  Ikol=1
2737  FOR I=1 TO Ntc
2738  E(I)=0
2739  Sum(I)=0
2740  NEXT I
2741  OUTPUT 709;"RST"
2742  FOR Ji=1 TO 20
2744  IF Ihm=0 THEN OUTPUT 709;"CONFMEAS TEMPT,500-511,USE 600"
2745  IF Ihm=1 THEN OUTPUT 709;"CONFMEAS TEMPT,300-305,USE 600"
2748  IF Ihm=0 THEN Ntc=12
2752  FOR I=1 TO Ntc
2756  ENTER 709;E(I)
2760  Sum(I)=Sum(I)+E(I)
```

```
2776   IF I=(9-Nsub) THEN Et1(Ji-1)=E(I)
2777   IF I=(10-Nsub) THEN Et2(Ji-1)=E(I)
2778   NEXT I
2780   NEXT Ji
2784   Kdl=0
2785   FOR I=1 TO Ntc
2788   IF I=(9-Nsub) OR I=(10-Nsub) THEN
2792   Eave=Sum(I)/20
2797   Sum(I)=0
2798   END IF
2800   IF I=(9-Nsub) THEN
2801   FOR Jk=0 TO 19
2804   IF ABS(Et1(Jk)-Eave)<.1 THEN
2808   Sum(I)=Sum(I)+Et1(Jk)
2812   ELSE
2816   Kdl=Kdl+1
2817   END IF
2819   NEXT Jk
2820   END IF
2822   IF I=(10-Nsub) THEN
2823   FOR Jk=0 TO 19
2825   IF ABS(Et2(Jk)-Eave)<.1 THEN
2826   Sum(I)=Sum(I)+Et2(Jk)
2828   ELSE
2829   Kdl=Kdl+1
2830   END IF
2832   NEXT Jk
2833   END IF
2836   IF I=(9-Nsub) OR I=(10-Nsub) THEN PRINT USING "4X,""Kdl = "",DD";Kdl
2837   IF Kdl>10 THEN
2838   BEEP
2840   BEEP
2844   PRINT USING "4X,""Too much scattering in data - repeat data set"""
2848   GOTO 2084
2852   END IF
2860   Emf(I)=Sum(I)/(20-Kdl)
2864   NEXT I
2868   IF Ihm=1 THEN
2872   Sum(1)=0
2876   OUTPUT 709;"CONFMEAS TEMPT,320,USE 600"
2884   FOR Kk=1 TO 20
2888   ENTER 709;E(Kk)
2892   Sum(1)=Sum(1)+E(Kk)
2896   NEXT Kk
2900   Emf(7)=ABS(Sum(1))/20
2904   END IF
2908   IF Ihm=0 THEN
2909   FOR I=1 TO 2
2910   Sum(I)=0
2911   NEXT I
2912   OUTPUT 709;"RST"
2913   FOR Ji=1 TO 5
2915   OUTPUT 709;"CONFMEAS DCV,512-513,USE 600"
2916   FOR I=1 TO 2
2920   ENTER 709;E(I)
2936   Sum(I)=Sum(I)+E(I)
2937   NEXT I
2940   NEXT Ji
2941   FOR I=1 TO 2
2944   IF I=1 THEN Vr=Sum(I)/5
```

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2948    IF I=2 THEN Ir=Sum(I)*1.9182/5
2952    NEXT I
2956    END IF
2960    ELSE
2964    IF Ihm=0 THEN ENTER @File2;Bop,Told,Emf(*),Vr,Ir
2968    IF Ihm=1 THEN ENTER @File2;Bop,Told,Emf(*),Fms
2972    END IF
2976!
2980! CONVERT emf'S TO TEMP,VOLT,CURRENT
2984    Twa=0
2988    FOR I=1 TO Ntc
2992    IF Idtc>0 THEN
2996    IF I=Ldtc1 OR I=Ldtc2 THEN
3000    T(I)=0
3004    GOTO 3044
3008    END IF
3012    END IF
3016    IF Itt<4 AND Ihm=0 THEN
3020    IF I>4 AND I<9 THEN
3024    T(I)=0
3028    GOTO 3044
3032    END IF
3036    END IF
3040    T(I)=Emf(I)
3044    NEXT I
3048    IF Itt<4 THEN
3052    FOR I=1 TO 4
3056    IF I=Ldtc1 OR I=Ldtc2 THEN
3060    Twa=Twa
3064    ELSE
3068    Twa=Twa+T(I)
3072    END IF
3076    NEXT I
3080    Twa=Twa/(4-Idtc)
3084    ELSE
3088    IF Ihm=1 THEN 3128
3092    FOR I=1 TO 8
3096    IF I=Ldtc1 OR I=Ldtc2 THEN
3100    Twa=Twa
3104    ELSE
3108    Twa=Twa+T(I)
3112    END IF
3116    NEXT I
3120    Tw=Twa/(8-Idtc)
3124    END IF
3128    Tld=T(9-Nsub)
3132    Tld2=T(10-Nsub)
3136    Tlda=(Tld+Tld2)*.5
3140    Tv=T(11-Nsub)
3158    Tsump=T(12-Nsub)
3160    IF Ihm=0 THEN 3176
3168    Tinlet=T(13-Nsub)
3172    Tout=T(14-Nsub)
3176    IF Ihm=0 THEN
3180    Amp=ABS(Ir)
3184    Volt=ABS(Vr)*25
3188    Q=Volt*Amp
3192    END IF
3196    IF Itt=0 AND Ihm=0 THEN
3200    Kcu=FNKcu(Tw)
```

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3204  ELSE
3208  Kcu=Kcua(Itt)
3212  END IF
3216!
3220! FOURIER CONDUCTION EQUATION WITH CONTACT RESISTANCE NEGLECTED
3224  IF Ihm=0 THEN Tw=Tw-Q*LOG(D2/D1)/(2*PI*Kcu*L)
3228  IF Ilqv=0 THEN Tsat=Tlda
3232  IF Ilqv=1 THEN Tsat=(Tlda+Tv)*.5
3236  IF Ilqv=2 THEN Tsat=Tv
3244  IF Ihm=1 THEN
3248  Tavg=Tinlet
3252  Grad=37.9853+.104388*Tavg
3256  Tdrop=ABS(Emf(7))*1.E+6/(10*Grad)
3260  Tavgc=Tinlet-Tdrop*.5
3264  IF ABS(Tavg-Tavgc)>.01 THEN
3268  Tavg=(Tavg+Tavgc)*.5
3272  GOTO 3252
3276  END IF
3280!
3284! COMPUTE WATER PROPERTIES
3288  IF Ihm=1 THEN
3292  Kw=FNKw(Tavg)
3296  Muwa=FNMuw(Tavg)
3300  Cpw=FNCpw(Tavg)
3304  Prw=FNPrw(Tavg)
3308  Rhow=FNRhow(Tavg)
3312  Twi=Tavg
3316!
3320! Compute MDOT
3324  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
3281  Mdot=Mdot*(1.0365-Tinlet*(1.96644E-3-Tinlet*5.252E-6))/1.0037
3332  Kdt=0
3336  Q=Mdot*Cpw*Tdrop
3340  Lmtd=Tdrop/LOG((Tinlet-Tsat)/(Tinlet-Tdrop-Tsat))
3344  Uo=Q/(PI*Do*L*Lmtd)
3348  Rw=Do*LOG(Do/Di)/(2.*Kcu)
3352  Tw=Tsat+Fr*Lmtd
3356  Vw=Mdot/(Rhow*PI*Di^2/4)
3360  Rew=Rhow*Vw*Di/Muwa
3364  Hi=Ci*Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
3368  Twic=Tavg-Q/(PI*Do*L*Hi)
3372  IF ABS(Twi-Twic)>.01 THEN
3376  Twi=(Twi+Twic)*.5
3380  GOTO 3364
3384  END IF
3388  Twi=(Twi+Twic)*.5
3392  Ho=1/(1/Uo-Do/(Di*Hi)-Rw)
3396  END IF
3397  END IF
3399  IF Ihm=1 THEN
3400  Thetab=Q/(Ho*PI*Do*L)
3404  Tw=Tsat+Thetab
3405  ELSE
3408  Thetab=Tw-Tsat
3411  END IF
3413  IF Thetab<0 THEN
3416  BEEP
3420  INPUT "TWALL<TSAT (0=CONTINUE, 1=END)",Iev
3424  IF Iev=0 THEN GOTO 2068
```

```
3428  IF Iev=1 THEN 3832
3432  END IF
3440!
3444! COMPUTE VARIOUS PROPERTIES
3452  Tfilm=(Tu+Tsat)*.5
3456  Rho=FNRho(Tfilm)
3460  Mu=FNMu(Tfilm)
3464  K=FNK(Tfilm)
3468  Cp=FNCp(Tfilm)
3472  Beta=FNBeta(Tfilm)
3476  Hfg=FNHfg(Tsat)
3480  Ni=Mu/Rho
3484  Alpha=K/(Rho*Cp)
3488  Pr=Ni/Alpha
3492  Psat=FNPsat(Tsat)
3496!
3500! COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
3504! FOR UNENHANCED END(S)
3508  Hbar=190
3512  Fe=(Hbar*P/(Kcu*A))^.5*Lu
3516  Tanh=FNTanh(Fe)
3520  Theta=Thetab*Tanh/Fe
3524  Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
3528  Yy=(1+(.559/Pr)^(9/16))^(8/27)
3532  Hbarc=K/Do*(.6+.387*Xx/Yy)^2
3536  IF ABS((Hbar-Hbarc)/Hbarc)>.001 THEN
3540  Hbar=(Hbar+Hbarc)*.5
3544  GOTO 3512
3548  END IF
3552!
3556! COMPUTE HEAT LOSS RATE THROUGH UNENHANCED END(S)
3560  Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
3564  Qc=Q-2*Q1
3568  As=PI*D2*L
3572!
3576! COMPUTE ACTUAL HEAT FLUX AND BOILING COEFFICIENT
3580  Qdp=Qc/As
3584  Htube=Qdp/Thetab
3588  Csf=(Cp*Thetab/Hfg)/(Qdp/(Mu*Hfg)*(.014/(9.81*Rho)^.5)^(1/3.)*Pr^1.7)
3592!
3596! RECORD TIME OF DATA TAKING
3600  IF Im=0 THEN
3604  OUTPUT 709;"TIMEDATE"
3608  ENTER 709;Told
3612  END IF
3616!
3620! OUTPUT DATA TO PRINTER
3624  PRINTER IS 701
3628  IF Iov=0 THEN
3632  PRINT
3636  PRINT USING "10X,""Data Set Number = "",DDD,2X,""Bulk Oil % = "",DD.D,5X,1
      4A";J,Bop,TIME$(Told)
3640  IF Ihm=0 THEN
3644  PRINT USING "10X,""TC No:    1       2       3       4       5       6       7
      8"""
3648  PRINT USING "10X,""Temp :"",8(1X,MDD.DD)";T(1),T(2),T(3),T(4),T(5),T(6),T(
      7),T(8)
3652  PRINT USING "10X,""  Twa    Tliqd   Tliqd2  Tvapr   Psat    Tsump"""
3656  PRINT USING "10X,2(MDD.DD,1X),1X,MDD.DD,1X,2(1X,MDD.DD),2X,MDD.D";Tw,Tld,T
      ld2,Tv,Psat,Tsump
```

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3660    PRINT USING "10X,"" Thetab   Htube       Qdp"""
3664    PRINT USING "10X,MDD.3D,1X,MZ.3DE,1X,MZ.3DE";Thetab,Htube,Qdp
3668    ELSE
3672    PRINT USING "10X,"" Fms     Vw   Tsat   Tinl Tdrop Thetab     q        Uo
        Ho"""
3676    PRINT USING "10X,4(2D.DD,1X),Z.3D,1X,DD.DD,1X,3(MZ.3DE,1X)";Fms,Vw,Tsat,Ti
nlet,Tdrop,Thetab,Qdp,Uo,Ho
3680    END IF
3684    END IF
3688    IF Iov=1 THEN
3692    IF J=1 THEN
3696    PRINT
3700    IF Ihm=0 THEN
3704    PRINT USING "10X,"" RUN No  Oil%  Tsat      Htube        Qdp          Thetab"""
3708    ELSE
3712    PRINT USING "10X,""  FMS    OIL%  TSAT      HTUBE        QDP          THETAB"""
3716    END IF
3720    END IF
3724    IF Ihm=0 THEN
3728    PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";J,Bop,Tsat,Htube,Qdp,The
tab
3732    ELSE
3736    PRINT USING "12X,3D,4X,DD,2X,MDD.DD,3(1X,MZ.3DE)";Fms,Bop,Tsat,Htube,Qdp,T
hetab
3740    END IF
3744    END IF
3748    IF Im=0 THEN
3752    BEEP
3756    INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Ok
3760    END IF
3764    IF Ok=1 OR Im=1 THEN J=J+1
3768    IF Ok=1 AND Im=0 THEN
3772    IF Ihm=0 THEN OUTPUT @File1;Bop,Told,Emf(*),Vr,Ir
3776    IF Ihm=1 THEN OUTPUT @File1;Bop,Told,Emf(*),Fms
3780    END IF
3784    IF Iuf=1 THEN OUTPUT @Ufile;Vw,Uo
3788    IF Ire=1 THEN OUTPUT @Refile;Fms,Rew
3792    IF (Im=1 OR Ok=1) AND Iplot=1 THEN OUTPUT @Plot;Qdp,Thetab
3796    IF Im=0 THEN
3800    BEEP
3804    INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
3808    Nrun=J
3812    IF Go_on=0 THEN 3832
3816    IF Go_on<>0 THEN Repeat
3820    ELSE
3824    IF J<Nrun+1 THEN Repeat
3828    END IF
3832    IF Im=0 THEN
3836    BEEP
3840    PRINT USING "10X,""NOTE: "",ZZ,"" data runs were stored in file "",10A";J-
1,D2_file$
3844    ASSIGN @File1 TO *
3848    OUTPUT @File2;Nrun-1
3852    ASSIGN @File1 TO D1_file$
3856    ENTER @File1;Dt,Ldtc1,Ldtc2,Itt
3860    OUTPUT @File2;Dt,Ldtc1,Ldtc2,Itt
3864    FOR I=1 TO Nrun-1
3868    IF Ihm=0 THEN
3872    ENTER @File1;Bop,Told,Emf(*),Vr,Ir
3876    OUTPUT @File2;Bop,Told,Emf(*),Vr,Ir
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```
3880  ELSE
3884  ENTER @File1;Bop,Told,Emf(*),Fms
3888  OUTPUT @File2;Bop,Told,Emf(*),Fms
3892  END IF
3896  NEXT I
3900  ASSIGN @File1 TO *
3904  PURGE "DUMMY"
3908  END IF
3912  BEEP
3916  PRINT
3920  IF Iplot=1 THEN PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in
      plot data file "",10A";J-1,P_file$
3924  ASSIGN @File2 TO *
3928  ASSIGN @Plot TO *
3932  IF Iuf=1 THEN ASSIGN @Ufile TO *
3936  IF Ire=1 THEN ASSIGN @Refile TO *
3940  CALL Stats
3944  BEEP
3948  INPUT "LIKE TO PLOT DATA (1=Y,0=N)?",Ok
3952  IF Ok=1 THEN CALL Plot
3956  SUBEND
3960  !
3964  ! CURVE FITS OF PROPERTY FUNCTIONS
3968  DEF FNKcu(T)
3972  ! OFHC COPPER 250 TO 300 K
3976  Tk=T+273.15    !C TO K
3980  K=434-.112*Tk
3984  RETURN K
3988  FNEND
3992  DEF FNMu(T)
3996  ! 170 TO 360 K CURVE FIT OF VISCOUSITY
4000  Tk=T+273.15    !C TO K
4004  Mu=EXP(-4.4636+(1011.47/Tk))*1.0E-3
4008  RETURN Mu
4012  FNEND
4016  DEF FNCp(T)
4020  ! 180 TO 400 K CURVE FIT OF Cp
4024  Tk=T+273.15    !C TO K
4028  Cp=.40188+1.65007E-3*Tk+1.51494E-6*Tk^2-6.67853E-10*Tk^3
4032  Cp=Cp*1000
4036  RETURN Cp
4040  FNEND
4044  DEF FNRho(T)
4048  Tk=T+273.15    !C TO K
4052  X=1-(1.8*Tk/753.95)   !K TO R
4056  Ro=36.32+61.146414*X^(1/3)+16.418015*X+17.476838*X^.5+1.119828*X^2
4060  Ro=Ro/.062428
4064  RETURN Ro
4068  FNEND
4072  DEF FNPr(T)
4076  Pr=FNCp(T)*FNMu(T)/FNK(T)
4080  RETURN Pr
4084  FNEND
4088  DEF FNK(T)
4092  ! T<360 K WITH T IN C
4096  K=.071-.000261*T
4100  RETURN K
4104  FNEND
4108  DEF FNTanh(X)
4112  P=EXP(X)
```

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```
4116  Q=1/P
4120  Tanh=(P-Q)/(P+Q)
4124  RETURN Tanh
4128  FNEND
4138 !
4184  DEF FNBeta(T)
4188  Rop=FNRho(T+.1)
4192  Rom=FNRho(T-.1)
4196  Beta=-2/(Rop+Rom)*(Rop-Rom)/.2
4200  RETURN Beta
4204  FNEND
4208  DEF FNHfg(T)
4212  Hfg=1.3741344E+5-T*(3.3094361E+2+T*1.2165143)
4216  RETURN Hfg
4220  FNEND
4224  DEF FNPsat(Tc)
4228 ! 0 TO 80 deg F CURVE FIT OF Psat
4232  Tf=1.8*Tc+32
4236  Pa=5.945525+Tf*(.15352082+Tf*(1.4840963E-3+Tf*9.6150671E-6))
4240  Pg=Pa-14.7
4244  IF Pg>0 THEN        ! +=PSIG,-=in Hg
4248  Psat=Pg
4252  ELSE
4256  Psat=Pg*29.92/14.7
4260  END IF
4264  RETURN Psat
4268  FNEND
4272  DEF FNHsmooth(X,Bop,Isat)
4276  DIM A(5),B(5),C(5),D(5)
4280  DATA .20526,.25322,.319048,.55322,.79909,1.00258
4284  DATA .74515,.72992,.73189,.71225,.68472,.64197
4288  DATA .41092,.17726,.25142,.54806,.81916,1.0845
4292  DATA .71403,.72913,.72565,.696691,.665867,.61889
4296  READ A(*),B(*),C(*),D(*)
4300  IF Bop<6 THEN I=Bop
4304  IF Bop=6 THEN I=4
4308  IF Bop=10 THEN I=5
4312  IF Isat=1 THEN
4316  Hs=EXP(A(I)+B(I)*LOG(X))
4320  ELSE
4324  Hs=EXP(C(I)+D(I)*LOG(X))
4328  END IF
4332  RETURN Hs
4336  FNEND
4340  DEF FNPoly(X)
4344  COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4348  X1=X
4352  Poly=B(0)
4356  FOR I=1 TO Nop
4360  IF Ilog=1 THEN X1=LOG(X)
4364  Poly=Poly+B(I)*X1^I
4368  NEXT I
4372  IF Ilog=1 THEN Poly=EXP(Poly)
4376  RETURN Poly
4380  FNEND
4384  SUB Poly
4388  DIM R(10),S(10),Sy(12),Sx(12),Xx(100),Yy(100)
4392  COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4396  COM /Xxyy/ Xp(25),Yp(25)
4400  FOR I=0 TO 4
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```
4404   B(I)-0
4408   NEXT I
4412   BEEP
4416   INPUT "SELECT (0-FILE,1-KEYBOARD,2-PROGRAM)",Im
4420   Im-Im+1
4424   BEEP
4428   INPUT "ENTER NUMBER OF X-Y PAIRS",Np
4432   IF Im-1 THEN
4436   BEEP
4440   INPUT "ENTER DATA FILE NAME",D_file$
4444   BEEP
4448   INPUT "LIKE TO EXCLUDE DATA PAIRS (1-Y,0-N)?",Ied
4452   IF Ied-1 THEN
4456   BEEP
4460   INPUT "ENTER NUMBER OF PAIRS TO BE EXCLUDED",Ipex
4464   END IF
4468   ASSIGN @File TO D_file$
4472   ELSE
4476   BEEP
4480   INPUT "WANT TO CREATE A DATA FILE (1-Y,0-N)?",Yes
4484   IF Yes-1 THEN
4488   BEEP
4492   INPUT "GIVE A NAME FOR DATA FILE",D_file$
4496   CREATE BDAT D_file$,5
4500   ASSIGN @File TO D_file$
4504   END IF
4508   END IF
4512   BEEP
4516   INPUT "ENTER THE ORDER OF POLYNOMIAL",N
4520   FOR I-0 TO N*2
4524   Sy(I)-0
4528   Sx(I)-0
4532   NEXT I
4536   IF Ied-1 AND Im-1 THEN
4540   FOR I-1 TO Ipex
4544   ENTER @File;X,Y
4548   NEXT I
4552   END IF
4556   FOR I-1 TO Np
4560   IF Im-1 THEN
4564   IF Opo-2 THEN ENTER @File;X,Y
4568   IF Opo<2 THEN ENTER @File;Y,X
4572   IF Opo-1 THEN Y-Y/X
4576   IF Ilog-1 THEN
4580   IF Opo-2 THEN Xt-X/Y
4584   X-LOG(X)
4588   IF Opo-2 THEN Y-LOG(Xt)
4592   IF Opo<2 THEN Y-LOG(Y)
4596   END IF
4600   END IF
4604   IF Im-2 THEN
4608   BEEP
4612   INPUT "ENTER NEXT X-Y PAIR",X,Y
4616   IF Yes-1 THEN OUTPUT @File;X,Y
4620   END IF
4624   IF Im<3 THEN
4628   Xx(I)-X
4632   Yy(I)-Y
4636   ELSE
4640   X-Xp(I-1)
```

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```
4644  Y=Yp(I-1)
4648  END IF
4652  R(0)=Y
4656  Sy(0)=Sy(0)+Y
4660  S(1)=X
4664  Sx(1)=Sx(1)+X
4668  FOR J=1 TO N
4672  R(J)=R(J-1)*X
4676  Sy(J)=Sy(J)+R(J)
4680  NEXT J
4684  FOR J=2 TO N*2
4688  S(J)=S(J-1)*X
4692  Sx(J)=Sx(J)+S(J)
4696  NEXT J
4700  NEXT I
4704  IF Yes=1 AND Im=2 THEN
4708  BEEP
4712  PRINT USING "12X,DD,"" X-Y pairs were stored in file "",10A";Np,D_file$
4716  END IF
4720  Sx(0)=Np
4724  FOR I=0 TO N
4728  C(I)=Sy(I)
4732  FOR J=0 TO N
4736  A(I,J)=Sx(I+J)
4740  NEXT J
4744  NEXT I
4748  FOR I=0 TO N-1
4752  CALL Divide(I)
4756  CALL Subtract(I+1)
4760  NEXT I
4764  B(N)=C(N)/A(N,N)
4768  FOR I=0 TO N-1
4772  B(N-1-I)=C(N-1-I)
4776  FOR J=0 TO I
4780  B(N-1-I)=B(N-1-I)-A(N-1-I,N-J)*B(N-J)
4784  NEXT J
4788  B(N-1-I)=B(N-1-I)/A(N-1-I,N-1-I)
4792  NEXT I
4796  !PRINTER IS 701
4800  !PRINT B(*)
4804  !PRINTER IS 705
4808  IF Iprnt=0 THEN
4812  PRINT USING "12X,""EXPONENT    COEFFICIENT"""
4816  FOR I=0 TO N
4820  PRINT USING "15X,DD,5X,MD.7DE";I,B(I)
4824  NEXT I
4828  PRINT " "
4832  PRINT USING "12X,""DATA POINT      X              Y        Y(CALCULATED) DISCR
EPANCY"""
4836  FOR I=1 TO Np
4840  Yc=B(0)
4844  FOR J=1 TO N
4848  Yc=Yc+B(J)*Xx(I)^J
4852  NEXT J
4856  D=Yy(I)-Yc
4860  PRINT USING "15X,3D,4X,4(MD.5DE,1X)";I,Xx(I),Yy(I),Yc,D
4864  NEXT I
4868  END IF
4872  ASSIGN @File TO *
4876  SUBEND
```

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4880   SUB Divide(M)
4884   COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4888   FOR I=M TO N
4892   Ao=A(I,M)
4896   FOR J=M TO N
4900   A(I,J)=A(I,J)/Ao
4904   NEXT J
4908   C(I)=C(I)/Ao
4912   NEXT I
4916   SUBEND
4920   SUB Subtract(K)
4924   COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4928   FOR I=K TO N
4932   FOR J=K-1 TO N
4936   A(I,J)=A(K-1,J)-A(I,J)
4940   NEXT J
4944   C(I)=C(K-1)-C(I)
4948   NEXT I
4952   SUBEND
4956   SUB Plin
4960   COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
4964   COM /Xxyy/ Xx(25),Yy(25)
4968   PRINTER IS 705
4972   BEEP
4976   INPUT "WANT TO PLOT Uo vs Vw? (1=Y,0=N)",Iuo
4980   IF Iuo=0 THEN
4984   BEEP
4988   INPUT "SELECT (0=h/h0% same tube,1=h(HF)/h(sm)",Irt
4992   BEEP
4996   INPUT "SELECT h/h RATIO (1=FILE,0=COMPUTED)",Ihrat
5000   IF Ihrat=0 THEN
5004   BEEP
5008   INPUT "WHICH Tsat (1=6.7,0=-2.2)",Isat
5012   END IF
5016   Xmin=0
5020   Xmax=10
5024   Xstep=2
5028   IF Irt=0 THEN
5032   Ymin=0
5036   Ymax=1.4
5040   Ystep=.2
5044   ELSE
5048   Ymin=0
5052   Ymax=15
5056   Ystep=5
5060   END IF
5064   ELSE
5068   Opo=2
5072   Ymin=0
5076   Ymax=12
5080   Ystep=3
5084   Xmin=0
5088   Xmax=4
5092   Xstep=1
5096   END IF
5100   IF Ihrat=1 THEN
5104   Ymin=0
5108   Ymax=18
5112   Ystep=3
5116   Xmin=0
```

```
5120  Xmax=9
5124  Xstep=2
5128  END IF
5132  BEEP
5136  PRINT "IN;SP1;IP 2300,2200,8300,6800;"
5140  PRINT "SC 0,100,0,100;TL 2,0;"
5144  Sfx=100/(Xmax-Xmin)
5148  Sfy=100/(Ymax-Ymin)
5152  PRINT "PU 0,0 PD"
5156  FOR Xa=Xmin TO Xmax STEP Xstep
5160  X=(Xa-Xmin)*Sfx
5164  PRINT "PA";X,",0; XT;"
5168  NEXT Xa
5172  PRINT "PA 100,0;PU;"
5176  PRINT "PU PA 0,0 PD"
5180  FOR Ya=Ymin TO Ymax STEP Ystep
5184  Y=(Ya-Ymin)*Sfy
5188  PRINT "PA 0,";Y,"YT"
5192  NEXT Ya
5196  PRINT "PA 0,100 TL 0 2"
5200  FOR Xa=Xmin TO Xmax STEP Xstep
5204  X=(Xa-Xmin)*Sfx
5208  PRINT "PA";X,",100; XT"
5212  NEXT Xa
5216  PRINT "PA 100,100 PU PA 100,0 PD"
5220  FOR Ya=Ymin TO Ymax STEP Ystep
5224  Y=(Ya-Ymin)*Sfy
5228  PRINT "PD PA 100,";Y,"YT"
5232  NEXT Ya
5236  PRINT "PA 100,100 PU"
5240  PRINT "PA 0,-2 SR 1.5,2"
5244  FOR Xa=Xmin TO Xmax STEP Xstep
5248  X=(Xa-Xmin)*Sfx
5252  PRINT "PA";X,",0;"
5256  IF Iuo=0 THEN PRINT "CP -2,-1;LB";Xa;""
5260  IF Iuo=1 THEN PRINT "CP -1.5,-1;LB";Xa;""
5264  NEXT Xa
5268  PRINT "PU PA 0,0"
5272  FOR Ya=Ymin TO Ymax STEP Ystep
5276  IF ABS(Ya)<1.E-5 THEN Ya=0
5280  Y=(Ya-Ymin)*Sfy
5284  PRINT "PA 0,";Y,""
5288  IF Iuo=0 THEN PRINT "CP -4,-.25;LB";Ya;""
5292  IF Iuo=1 THEN PRINT "CP -3,-.25;LB";Ya;""
5296  NEXT Ya
5300  Xlabel$="Oil Percent"
5304  IF Iuo=0 THEN
5308  IF Irt=0 THEN
5312  Ylabel$="h/h0%"
5316  ELSE
5320  Ylabel$="h/hsmooth"
5324  END IF
5328  PRINT "SR 1.5,2;PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
5332  PRINT "PA -11,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
5336  PRINT "CP 0,0"
5340  ELSE
5344  PRINT "SP0;SP2"
5348  PRINT "SR 1.2,2.4;PU PA -8,35;DI 0,1;LBU;PR 1,0.5;LBo;PR -1,0.5;LB (kW/m
"
5352  PRINT "PR -1,0.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
```

```
5356   PRINT "PA 42,-10;DI 1,0;LBV;PR .4,-1;LBw;PR 1,.5;LB(m/s)"
5360   PRINT "SP0;SP1"
5364   END IF
5368   Ipn=0
5372   BEEP
5376   INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Okp
5380   Icn=0
5384   IF Okp=1 THEN
5388   BEEP
5392   INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
5396!  IF Iuo=0 THEN
5400   BEEP
5404   INPUT "SELECT (0=LINEAR, 1=LOG(X,Y)",Ilog
5408!  END IF
5412   ASSIGN @File TO D_file$
5416   BEEP
5420   INPUT "ENTER THE BEGINNING RUN NUMBER",Md
5424   BEEP
5428   INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
5432   IF Iuo=0 AND Ihrat=0 THEN
5436   BEEP
5440   INPUT "ENTER DESIRED HEAT FLUX",Q
5444   END IF
5448   BEEP
5452   PRINTER IS 1
5456   PRINT USING "4X,""Select a symbol:"""
5460   PRINT USING "4X,""1  Star    2  Plus sign"""
5464   PRINT USING "4X,""3  Circle 4  Square"""
5468   PRINT USING "4X,""5  Rombus"""
5472   PRINT USING "4X,""6  Right-side-up triangle"""
5476   PRINT USING "4X,""7  Up-side-down triangle"""
5480   INPUT Sym
5484   PRINTER IS 705
5488   PRINT "PU DI"
5492   IF Sym=1 THEN PRINT "SM*"
5496   IF Sym=2 THEN PRINT "SM+"
5500   IF Sym=3 THEN PRINT "SMo"
5504   Nn=4
5508   IF Ilog=1 THEN Nn=1
5512   IF Md>1 THEN
5516   FOR I=1 TO (Md-1)
5520   ENTER @File;Xa,Ya
5524   NEXT I
5528   END IF
5532   IF Ihrat=0 THEN
5536   Q1=Q
5540   IF Ilog=1 THEN Q=LOG(Q)
5544   END IF
5548   FOR I=1 TO Npairs
5552   IF Iuo=0 AND Ihrat=0 THEN
5556   ENTER @File;Xa,B(*)
5560   Ya=B(0)
5564   FOR K=1 TO Nn
5568   Ya=Ya+B(K)*Q^K
5572   NEXT K
5576   END IF
5580   IF Iuo=1 OR Ihrat=1 THEN
5584   ENTER @File;Xa,Ya
5588   IF Iuo=1 THEN Ya=Ya/1000
5592   END IF
```

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```
5596  IF Iuo=0 AND Ihrat=0 THEN
5600  IF Ilog=1 THEN Ya=EXP(Ya)
5604  IF Ilog=0 THEN Ya=Q1/Ya
5608  IF Irt=0 THEN
5612  IF Xa=0 THEN
5616  Yo=Ya
5620  Ya=1
5624  ELSE
5628  Ya=Ya/Yo
5632  END IF
5636  ELSE
5640  Hsm=FNHsmooth(Q,Xa,Isat)
5644  Ya=Ya/Hsm
5648  END IF
5652  END IF
5656  Xx(I-1)=Xa
5660  Yy(I-1)=Ya
5664  X=(Xa-Xmin)*Sfx
5668  Y=(Ya-Ymin)*Sfy
5672  IF Sym>3 THEN PRINT "SM"
5676  IF Sym<4 THEN PRINT "SR 1.4,2.4"
5680  PRINT "PA",X,Y,""
5684  IF Sym>3 THEN PRINT "SR 1.2,1.6"
5688  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0,;"
5692  IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
5696  IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
5700  IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
5704  NEXT I
5708  BEEP
5712  ASSIGN @File TO *
5716  END IF
5720  PRINT "PU SM"
5724  BEEP
5728  INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Okp
5732  IF Okp=1 THEN
5736  BEEP
5740  PRINTER IS 1
5744  PRINT USING "4X,""Select line type:"""
5748  PRINT USING "6X,""0    Solid line"""
5752  PRINT USING "6X,""1    Dashed"""
5756  PRINT USING "6X,""2,,,5 Longer line - dash"""
5760  INPUT Ipn
5764  PRINTER IS 70S
5768  BEEP
5772  INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
5776  Iprnt=1
5780  CALL Poly
5784  IF Iuo=1 THEN
5788  BEEP
5792  INPUT "DESIRE TO SET X Lower and Upper Limit (1=Y,0=N)?",Ixlim
5796  IF Ixlim=0 THEN
5800  Xll=0
5804  Xul=7
5808  END IF
5812  IF Ixlim=1 THEN
5816  BEEP
5820  INPUT "ENTER X Lower Limit",Xll
5824  BEEP
5828  INPUT "ENTER X Upper Limit",Xul
5832  END IF
```

```
5836    END IF
5840    FOR Xa=Xll TO Xul STEP Xstep/ZS
5844    Icn=Icn+1
5848    Ya=FNPoly(Xa)
5852    IF Iuo=1 THEN Ya=Ya/1000
5856    Y=(Ya-Ymin)*Sfy
5860    X=(Xa-Xmin)*Sfx
5864    IF Y<0 THEN Y=0
5868    IF Y>100 THEN GOTO 5908
5872    Pu=0
5876    IF Ipn=1 THEN Idf=Icn MOD 2
5880    IF Ipn=2 THEN Idf=Icn MOD 4
5884    IF Ipn=3 THEN Idf=Icn MOD 8
5888    IF Ipn=4 THEN Idf=Icn MOD 16
5892    IF Ipn=5 THEN Idf=Icn MOD 32
5896    IF Idf=1 THEN Pu=1
5900    IF Pu=0 THEN PRINT "PA",X,Y,"PD"
5904    IF Pu=1 THEN PRINT "PA",X,Y,"PU"
5908    NEXT Xa
5912    PRINT "PU"
5916    GOTO 5372
5920    END IF
5924    BEEP
5928    INPUT "WANT TO QUIT (1=Y,0=N)?",Iquit
5932    IF Iquit=1 THEN 5940
5936    GOTO 5372
5940    PRINT "PU SP0"
5944    SUBEND
5948    SUB Stats
5952    PRINTER IS 701
5956    J=0
5960    K=0
5964    BEEP
5968    IF Iplot=1 THEN ASSIGN @File TO P_file$
5972    BEEP
5976    INPUT "LAST RUN No?(0=QUIT)",Nn
5980    IF Nn=0 THEN 6124
5984    Nn=Nn-J
5988    Sx=0
5992    Sy=0
5996    Sz=0
6000    Sxs=0
6004    Sys=0
6008    Szs=0
6012    FOR I=1 TO Nn
6016    J=J+1
6020    ENTER @File;Q,T
6024    H=Q/T
6028    Sx=Sx+Q
6032    Sxs=Sxs+Q^2
6036    Sy=Sy+T
6040    Sys=Sys+T^2
6044    Sz=Sz+H
6048    Szs=Szs+H^2
6052    NEXT I
6056    Qave=Sx/Nn
6060    Tave=Sy/Nn
6064    Have=Sz/Nn
6068    Sdevq=SQR(ABS((Nn*Sxs-Sx^2)/(Nn*(Nn-1))))
6072    Sdevt=SQR(ABS((Nn*Sys-Sy^2)/(Nn*(Nn-1))))
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6076    Sdevh=SQR(ABS((Nn*Szs-Sz^2)/(Nn*(Nn-1))))
6080    Sh=100*Sdevh/Have
6084    Sq=100*Sdevq/Qave
6088    St=100*Sdevt/Tave
6092    IF K=1 THEN 6116
6096    PRINT
6100    PRINT USING "11X,""DATA FILE:"",14A";File$
6104    PRINT
6108    PRINT USING "11X,""RUN Htube      SdevH   Qdp        SdevQ   Thetab SdevT""
"
6112    K=1
6116    PRINT USING "11X,DD,2(2X,D.3DE,1X,3D.2D),2X,DD.3D,1X,3D.2D";J,Have,Sh,Qave
,Sq,Tave,St
6120    GOTO 5972
6124    ASSIGN @File1 TO *
6128    PRINTER IS 1
6132    SUBEND
6136    SUB Coef
6140    COM /Cply/ A(10,10),C(10),B(5),N,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
6144    BEEP
6148    INPUT "GIVE A NAME FOR CROSS-PLOT FILE",Cpf$
6152    CREATE BDAT Cpf$,2
6156    ASSIGN @File TO Cpf$
6160    BEEP
6164    INPUT "SELECT (0=LINEAR,1=LOG(X,Y))",Ilog
6168    BEEP
6172    INPUT "ENTER OIL PERCENT (-1=STOP)",Bop
6176    IF Bop<0 THEN 6192
6180    CALL Poly
6184    OUTPUT @File;Bop,B(*)
6188    GOTO 6168
6192    ASSIGN @File TO *
6196    SUBEND
6200    SUB Wilson(Cf,Ci)
6204    COM /Wil/ D2,Di,Do,L,Lu,Kcu
6208    DIM Emf(12)
6212 !  WLISON PLOT SUBROUTINE DETERMINE CF AND CI
6216    BEEP
6220    INPUT "ENTER DATA FILE NAME",File$
6224    BEEP
6228    PRINTER IS 1
6232    PRINT USING "4X,""Select option:"""
6236    PRINT USING "4X,""  0 Vary Cf and  Ci"""
6240    PRINT USING "4X,""  1 Fix  Cf Vary Ci"""
6244    PRINT USING "4X,""  2 Vary Cf Fix  Ci"""
6248    INPUT "ENTER OPTION",Icfix
6252    PRINTER IS 701
6256    IF Icfix=0 THEN 6272
6260    IF Icfix>0 THEN BEEP
6264    IF Icfix=1 THEN INPUT "ENTER Cf",Csf
6268    IF Icfix=2 THEN INPUT "ENTER CI",Ci
6272    PRINTER IS 1
6276    INPUT "Want To Vary Coeff?(1=Y,0=N)",Iccoef
6280    IF Iccoef=1 THEN INPUT "ENTER COEFF",R
6284    PRINTER IS 701
6288    IF Icfix=0 OR Icfix=2 THEN Cfa=.004
6292    IF Icfix=1 THEN Cfa=Csf
6296    Cia=Ci
6300    Xn=.8
6304    Fr=.3
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6308  Jj=0
6312  Rr=3.
6316  IF Iccoef=1 THEN Rr=R
6320  PRINTER IS 1
6324  PRINT Do,Di,Kcu
6328  ASSIGN @File TO File$
6332  ENTER @File;Nrun,Dt,Ldtc1,Ldtc2,Itt
6336  Rw=Do*LOG(Do/Di)/(2*Kcu)
6340  Sx=0
6344  Sy=0
6348  Sxy=0
6352  Sx2=0
6356  Sy2=0
6360  FOR I=1 TO Nrun
6364  ENTER @File;Bop,TIME$(Told),Emf(*),Fms
6368! CONVERT EMF'S TO TEMPERATURE
6372  FOR J=1 TO 5
6376  T(J)=FNTvsv(Emf(J))
6380  NEXT J
6384  Tsat=(T(1)+T(2))*.5
6388  Tavg=T(5)
6392  Grad=37.9853+.104388*Tavg
6396  Tdrop=Emf(7)*1.E+6/(10.*Grad)
6400  Tavgc=T(5)-Tdrop*.5
6404  IF ABS(Tavg-Tavgc)>.01 THEN
6408  Tavg=(Tavg+Tavgc)*.5
6412  GOTO 6392
6416  END IF
6420!
6424! Compute properties of water
6428  Kw=FNKw(Tavg)
6432  Muwa=FNMuw(Tavg)
6436  Cpw=FNCpw(Tavg)
6440  Prw=FNPrw(Tavg)
6444  Rhow=FNRhow(Tavg)
6448!
6452! Compute properties of Freon-114
6456  Lmtd=Tdrop/LOG((T(5)-Tsat)/(T(5)-Tdrop-Tsat))
6460  IF Jj=0 THEN
6464  Tw=Tsat+Fr*Lmtd
6468  Thetab=Tw-Tsat
6472  Jj=1
6476  END IF
6480  Tf=(Tw+Tsat)*.5
6484  Rho=FNRho(Tf)
6488  Mu=FNMu(Tf)
6492  K=FNK(Tf)
6496  Cp=FNCp(Tf)
6500  Beta=FNBeta(Tf)
6504  Hfg=FNHfg(Tsat)
6508  Ni=Mu/Rho
6512  Alpha=K/(Rho*Cp)
6516  Pr=Ni/Alpha
6520!
6524! Analysis
6528! COMPUTE MDOT
6532  A=PI*(Do^2-Di^2)/4
6536  P=PI*Do
6540  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
```

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```
6544    Q=Mdot*Cpw*Tdrop
6548!   COMPUTE NATURAL-CONVECTIVE HEAT-TRANSFER COEFFICIENT
6552!   FOR UNENHANCED END(S)
6556    Hbar=190
6560    Fe=(Hbar*P/(Kcu*A))^.5*Lu
6564    Tanh=FNTanh(Fe)
6568    Theta=Thetab*Tanh/Fe
6572    Xx=(9.81*Beta*Thetab*Do^3*Tanh/(Fe*Ni*Alpha))^.166667
6576    Yy=(1+(.559/Pr)^(9/16))^(8/27)
6580    Hbarc=K/Do*(.6+.387*Xx/Yy)^2
6584    IF ABS((Hbar-Hbarc)/Hbar)>.001 THEN
6588    Hbar=(Hbar+Hbarc)*.5
6592    GOTO 6560
6596    END IF
6600!
6604!   COMPUTE HEAT LOSS RATE THROUGH UNENHANCED ENDS
6608    Q1=(Hbar*P*Kcu*A)^.5*Thetab*Tanh
6612    Qc=Q-2*Q1
6616    As=PI*D2*L
6620!   COMPUTE ACTUAL HEAT FLUX
6624    Qdp=Qc/As
6628    IF Icfix=0 OR Icfix>1 THEN Csf=1/Cf^(1./Rr)
6632    Thetab=Csf/Cp*Hfg*(Qdp/(Mu*Hfg)*(.014/(9.81*Rho))^.5)^(1/Rr)*Pr^1.7
6636    Ho=Qdp/Thetab
6640    Omega=Ho/Cf
6644    Uo=Q/(PI*Do*L*Lmtd)
6648    Vw=Mdot/(Rhow*PI*Di^2/4)
6652    Rew=Rhow*Vw*Di/Muwa
6656    Twi=Tw+Q*Rw/(PI*Do*L)
6660    Gama=Kw/Di*Rew^.8*Prw^(1/3.)*(Muwa/FNMuw(Twi))^.14
6664!   PRINTER IS 1
6668    Yw=(1./Uo-Rw)*Omega
6672    Xw=Omega*Do/(Gama*Di)
6676    Sx=Sx+Xw
6680    Sy=Sy+Yw
6684    Sxy=Sxy+Yw*Xw
6688    Sx2=Sx2+Xw*Xw
6692    Sy2=Sy2+Yw*Yw
6696    NEXT I
6700    ASSIGN @File TO *
6704    M=(Sx*Sy-Nrun*Sxy)/(Sx*Sx-Nrun*Sx2)
6708    C=(Sy-Sx*M)/Nrun
6712    IF Icfix=0 OR Icfix=3 OR Icfix=4 THEN
6716    Cic=1/M
6720    Cfc=1/C
6724    END IF
6728    IF Icfix=1 THEN
6732    Cic=1/M
6736    Cfc=Cf
6740    END IF
6744    IF Icfix=2 THEN
6748    Cic=Ci
6752    Cfc=1/C
6756    END IF
6760    IF ABS((Ci-Cic)/Cic)>.001 OR ABS((Cf-Cfc)/Cfc)>.001 THEN
6764    Ci=(Ci+Cic)*.5
6768    Cf=(Cf+Cfc)*.5
6772    PRINTER IS 1
6776    PRINT USING "2X,"" Csf = "",MZ.3DE,2X,"" Ci = "",MZ.3DE";Csf,Ci
6780    PRINTER IS 701
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```
6784    GOTO 6328
6788    END IF
6792    PRINT
6796    PRINTER IS 701
6800    PRINT USING "23X,""   Cf           Ci"""
6804    PRINT USING "8X,""ASSUMED       "",MZ.3DE,3X,MZ.3DE";Cfa,Cia
6808    PRINT USING "8X,""CALCULATED    "",MZ.3DE,3X,MZ.3DE";Csf,Ci
6812    PRINT
6816    Sum2=Sy2-2*M*Sxy-2*C*Sy+M^2*Sx2+2*M*C*Sx+Nrun*C^2
6820    PRINT USING "10X,""Sum of Squares = "",Z.3DE";Sum2
6824    PRINT USING "10X,""Coefficient = "",D.DDD";Rr
6828    SUBEND
6832    DEF FNMuw(T)
6836    A=247.8/(T+133.15)
6840    Mu=2.4E-5*10^A
6844    RETURN Mu
6848    FNEND
6852    DEF FNCpw(T)
6856    Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
6860    RETURN Cpw*1000
6864    FNEND
6868    DEF FNRhow(T)
6872    Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
6876    RETURN Ro
6880    FNEND
6884    DEF FNPrw(T)
6888    Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
6892    RETURN Prw
6896    FNEND
6900    DEF FNKw(T)
6904    X=(T+273.15)/273.15
6908    Kw=-.92247+X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
6912    RETURN Kw
6916    FNEND
6920    SUB Plot
6924    COM /Cply/ A(10,10),C(10),B(5),Nop,Iprnt,Opo,Ilog,Ifn,Ijoin,Njoin
6928    DIM Bs(3)
6932    INTEGER Ii
6936    PRINTER IS 1
6940    Idv=0
6944    BEEP
6948    INPUT "LIKE DEFAULT VALUES FOR PLOT (1=Y,0=N)?",Idv
6952    Opo=0
6956    BEEP
6960    PRINT USING "4X,""Select Option:"""
6964    PRINT USING "6X,""0  q versus delta-T"""
6968    PRINT USING "6X,""1  h versus delta-T"""
6972    PRINT USING "6X,""2  h versus q"""
6976    INPUT Opo
6980    BEEP
6984    INPUT "SELECT UNITS (0=SI,1=ENGLISH)",Iun
6988    PRINTER IS 705
6992    IF Idv<>1 THEN
6996    BEEP
7000    INPUT "ENTER NUMBER OF CYCLES FOR X-AXIS",Cx
7004    BEEP
7008    INPUT "ENTER NUMBER OF CYCLES FOR Y-AXIS",Cy
7012    BEEP
7016    INPUT "ENTER MIN X-VALUE (MULTIPLE OF 10)",Xmin
7020    BEEP
```

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```
7024    INPUT "ENTER MIN Y-VALUE (MULTIPLE OF 10)",Ymin
7028    ELSE
7032    IF Opo=0 THEN
7036    Cy=3
7040    Cx=3
7044    Xmin=.1
7048    Ymin=100
7052    END IF
7056    IF Opo=1 THEN
7060    Cy=2
7064    Cx=2
7068    Xmin=.1
7072    Ymin=100
7076    END IF
7080    IF Opo=2 THEN
7081    IF Iun=0 THEN
7084    Cy=3
7088    Cx=2
7092    Xmin=1000
7096    Ymin=100
7097    ELSE
7098    Cy=3
7099    Cx=3
7100    Xmin=100
7101    Ymin=10
7102    END IF
7104    END IF
7105    END IF
7108    BEEP
7112    PRINT "IN;SP1;IP 2300,2200,8300,6800;"
7116    PRINT "SC 0,100,0,100;TL 2,0;"
7120    Sfx=100/Cx
7124    Sfy=100/Cy
7128    BEEP
7132    INPUT "WANT TO BY-PASS CAGE? (1=Y,0=N)",Ibyp
7136    IF Ibyp=1 THEN 7632
7140    PRINT "PU 0,0 PD"
7144    Nn=9
7148    FOR I=1 TO Cx+1
7152    Xat=Xmin*10^(I-1)
7156    IF I=Cx+1 THEN Nn=1
7160    FOR J=1 TO Nn
7164    IF J=1 THEN PRINT "TL 2 0"
7168    IF J=2 THEN PRINT "TL 1 0"
7172    Xa=Xat*J
7176    X=LGT(Xa/Xmin)*Sfx
7180    PRINT "PA";X,",0; XT;"
7184    NEXT J
7188    NEXT I
7192    PRINT "PA 100,0;PU;"
7196    PRINT "PU PA 0,0 PD"
7200    Nn=9
7204    FOR I=1 TO Cy+1
7208    Yat=Ymin*10^(I-1)
7212    IF I=Cy+1 THEN Nn=1
7216    FOR J=1 TO Nn
7220    IF J=1 THEN PRINT "TL 2 0"
7224    IF J=2 THEN PRINT "TL 1 0"
7228    Ya=Yat*J
7232    Y=LGT(Ya/Ymin)*Sfy
```

```
7236    PRINT "PA 0,";Y,"YT"
7240    NEXT J
7244    NEXT I
7248    PRINT "PA 0,100 TL 0 2"
7252    Nn=9
7256    FOR I=1 TO Cx+1
7260    Xat=Xmin*10^(I-1)
7264    IF I=Cx+1 THEN Nn=1
7268    FOR J=1 TO Nn
7272    IF J=1 THEN PRINT "TL 0 2"
7276    IF J>1 THEN PRINT "TL 0 1"
7280    Xa=Xat*J
7284    X=LGT(Xa/Xmin)*Sfx
7288    PRINT "PA";X,",100; XT"
7292    NEXT J
7296    NEXT I
7300    PRINT "PA 100,100 PU PA 100,0 PD"
7304    Nn=9
7308    FOR I=1 TO Cy+1
7312    Yat=Ymin*10^(I-1)
7316    IF I=Cy+1 THEN Nn=1
7320    FOR J=1 TO Nn
7324    IF J=1 THEN PRINT "TL 0 2"
7328    IF J>1 THEN PRINT "TL 0 1"
7332    Ya=Yat*J
7336    Y=LGT(Ya/Ymin)*Sfy
7340    PRINT "PD PA 100,";Y,"YT"
7344    NEXT J
7348    NEXT I
7352    PRINT "PA 100,100 PU"
7356    PRINT "PA 0,-2 SR 1.5,2"
7360    Ii=LGT(Xmin)
7364    FOR I=1 TO Cx+1
7368    Xa=Xmin*10^(I-1)
7372    X=LGT(Xa/Xmin)*Sfx
7376    PRINT "PA";X,",0;"
7380    IF Ii>=0 THEN PRINT "CP -2,-2;LB10;PR -2,2;LB";Ii;""
7384    IF Ii<0 THEN PRINT "CP -2,-2;LB10;PR 0,2;LB";Ii;""
7388    Ii=Ii+1
7392    NEXT I
7396    PRINT "PU PA 0,0"
7400    Ii=LGT(Ymin)
7404    Y10=10
7408    FOR I=1 TO Cy+1
7412    Ya=Ymin*10^(I-1)
7416    Y=LGT(Ya/Ymin)*Sfy
7420    PRINT "PA 0,";Y,""
7424    PRINT "CP -4,-.25;LB10;PR -2,2;LB";Ii;""
7428    Ii=Ii+1
7432    NEXT I
7436    BEEP
7440    INPUT "WANT USE DEFAULT LABELS (1=Y,0=N)?",Idl
7444    IF Idl<>1 THEN
7448    BEEP
7452    INPUT "ENTER X-LABEL",Xlabel$
7456    BEEP
7460    INPUT "ENTER Y-LABEL",Ylabel$
7464    END IF
7468    IF Opo<2 THEN
7472    PRINT "SR 1,2;PU PA 40,-14;"
```

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```
7476  PRINT "LB(T;PR -1.6,3 PD PR 1.2,0 PU;PR .5,-4;LBwo;PR .5,1;"
7480  PRINT "LB-T;PR .5,-1;LBsat;PR .5,1;"
7484  IF Iun=0 THEN
7488  PRINT "LB) (K)"
7492  ELSE
7496  PRINT "LB) (F)"
7500  END IF
7504  END IF
7508  IF Opo=2 THEN
7512  IF Iun=0 THEN
7516  PRINT "SR 1.5,2;PU PA 40,-14;LBq (W/m;SR 1,1.5;PR 0.5,1;LB2;SR 1.5,2;PR
0.5,-1;LB)"
7520  ELSE
7524  PRINT "SR 1.5,2;PU PA 34,-14;LBq (Btu/hr;PR .5,.5;LB.;PR .5,-.5;"
7528  PRINT "LBft;PR .5,1;SR 1,1.5;LB2;SR 1.5,2;PR .5,-1;LB);"
7532  END IF
7536  END IF
7540  IF Opo=0 THEN
7544  IF Iun=0 THEN
7548  PRINT "SR 1.5,2;PU PA -12,40;DI 0,1;LBq (W/m;PR -1,0.5;SR 1,1.5;LB2;SR 1
.5,2;PR 1,.5;LB)"
7552  ELSE
7556  PRINT "SR 1.5,2;PU PA -12,32;DI 0,1;LBq (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
7560  PRINT "LBft;SR 1,1.5;PR -1,.5;LB2;PR 1,.5;SR 1.5,2;LB)"
7564  END IF
7568  END IF
7572  IF Opo>0 THEN
7576  IF Iun=0 THEN
7580! PRINT "SR 1.5,2;PU PA -12,38;DI 0,1;LBh (W/m;PR -1,.5;SR 1,1.5;LB2;SR 1.
5,2;PR .5,.5;"
7584  PRINT "SR 1.2,2.4;PU PA -12,37;DI 0,1;LBh;PR 1,0.5;LBo;PR -1,0.5;LB (W/m
"
7588  PRINT "PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,0;LBK)"
7592  ELSE
7596  PRINT "SR 1.5,2;PU PA -12,28;DI 0,1;LBh (Btu/hr;PR -.5,.5;LB.;PR .5,.5;"
7600  PRINT "LBft;PR -1,.5;SR 1,1.5;LB2;SR 1.5,2;PR .5,.5;LB.;PR .5,.5;LBF)"
7604  END IF
7608  END IF
7612  IF Idl=0 THEN
7616  PRINT "SR 1.5,2;PU PA 50,-16 CP";-LEN(Xlabel$)/2;"0;LB";Xlabel$;""
7620  PRINT "PA -14,50 CP 0,";-LEN(Ylabel$)/2*5/6;"DI 0,1;LB";Ylabel$;""
7624  PRINT "CP 0,0 DI"
7628  END IF
7632  Ipn=0
7636  Xll=1.E+6
7640  Xul=-1.E+6
7644  Icn=0
7648  Ifn=0
7652  Ijoin=1
7656  BEEP
7660  INPUT "WANT TO PLOT DATA FROM A FILE (1=Y,0=N)?",Ok
7664  IF Ok=1 THEN
7668  BEEP
7672  INPUT "ENTER THE NAME OF THE DATA FILE",D_file$
7676  ASSIGN @File TO D_file$
7680  BEEP
7684  BEEP
7688  INPUT "ENTER THE BEGINNING RUN NUMBER",Md
7692  BEEP
7696  INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
```

```
7700! BEEP
7704! INPUT "CONNECT DATA WITH LINE (1=Y,0=N)?",Icl
7708  BEEP
7712  PRINTER IS 1
7716  PRINT USING "4X,""Select a symbol:"""
7720  PRINT USING "6X,""1  Star     2  Plus sign"""
7724  PRINT USING "6X,""3  Circle   4  Square"""
7728  PRINT USING "6X,""5  Rombus"""
7732  PRINT USING "6X,""6  Right-side-up triangle"""
7736  PRINT USING "6X,""7  Up-side-down triangle"""
7740  INPUT Sym
7744  PRINTER IS 705
7748  PRINT "PU DI"
7752  IF Sym=1 THEN PRINT "SM•"
7756  IF Sym=2 THEN PRINT "SM+"
7760  IF Sym=3 THEN PRINT "SMo"
7764  IF Md>1 THEN
7768  FOR I=1 TO (Md-1)
7772  ENTER @File;Ya,Xa
7776  NEXT I
7780  END IF
7784  FOR I=1 TO Npairs
7788  ENTER @File;Ya,Xa
7792  IF I=1 THEN Q1=Ya
7796  IF I=Npairs THEN Q2=Ya
7800  IF Opo=1 THEN Ya=Ya/Xa
7804  IF Opo=2 THEN
7808  Q=Ya
7812  Ya=Ya/Xa
7816  Xa=Q
7820  END IF
7824  IF Xa<Xll THEN Xll=Xa
7828  IF Xa>Xul THEN Xul=Xa
7832  IF Iun=1 THEN
7836  IF Opo<2 THEN Xa=Xa•1.8
7840  IF Opo>0 THEN Ya=Ya•.1761
7844  IF Opo=0 THEN Ya=Ya•.317
7848  IF Opo=2 THEN Xa=Xa•.317
7852  END IF
7856  X=LGT(Xa/Xmin)•Sfx
7860  Y=LGT(Ya/Ymin)•Sfy
7864  Kj=0
7868  CALL Symb(X,Y,Sym,Icl,Kj)
7872  GOTO 7924
7876  IF Sym>3 THEN PRINT "SM"
7880  IF Sym<4 THEN PRINT "SR 1.4,2.4"
7884  IF Icl=0 THEN
7888  PRINT "PA",X,Y,""
7892  ELSE
7896  PRINT "PA",X,Y,"PD"
7900  END IF
7904  IF Sym>3 THEN PRINT "SR 1.2,1.6"
7908  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
7912  IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
7916  IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
7920  IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
7924  NEXT I
7928  PRINT "PU"
7932  BEEP
7936  INPUT "WANT TO LABEL? (1=Y,0=N)",Ilab
```

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```
7940  IF Ilab=1 THEN
7944  PRINT "SP0;SPZ"
7948  BEEP
7952  IF Klab=0 THEN
7956  Xlab=5
7960  Ylab=85
7964  INPUT "ENTER INITIAL X,Y LOCATIONS",Xlab,Ylab
7968  Xtt=Xlab-5
7972  Ytt=Ylab+8
7976  PRINT "SR 1,1.5"
7980  PRINT "SM;PA",Xtt,Ytt,"LB          X    Heat    File"
7984  Ytt=Ytt-3
7988  PRINT "PA",Xtt,Ytt,"LB        Oil  Flux  Name"
7992  IF Sym=1 THEN PRINT "SM."
7996  IF Sym=2 THEN PRINT "SM+"
8000  IF Sym=3 THEN PRINT "SMo"
8004  Klab=1
8008  END IF
8012  Kj=1
8016  CALL Symb(Xlab,Ylab,Sym,Icl,Kj)
8020  PRINT "SR 1,1.5;SM"
8024  IF Sym<4 THEN PRINT "PR 2,0"
8028  BEEP
8032  INPUT "ENTER BOP",Bop
8036  IF Bop<10 THEN PRINT "PR 2,0;LB";Bop;""
8040  IF Bop>9 THEN PRINT "PR .5,0;LB";Bop;""
8044  Ihf=0
8048  IF Q1>Q2 THEN Ihf=1
8052  IF Ihf=0 THEN PRINT "PR 4,0;LBInc"
8056  IF Ihf=1 THEN PRINT "PR 4,0;LBDec"
8060  PRINT "PR 2,0;LB";D_file$;""
8064  PRINT "SP0;SP1;SR 1.5,2"
8068  Ylab=Ylab-5
8072  END IF
8076  BEEP
8080  ASSIGN @File TO *
8084  X11=X11/1.2
8088  Xul=Xul*1.2
8092! GOTO 8040
8096  END IF
8100  PRINT "PU SM"
8104  BEEP
8108  INPUT "WANT TO PLOT A POLYNOMIAL (1=Y,0=N)?",Go_on
8112  IF Go_on=1 THEN
8116  BEEP
8120  PRINTER IS 1
8124  PRINT USING "4X,""Select line type:"""
8128  PRINT USING "6X,""0      Solid line"""
8132  PRINT USING "6X,""1      Dashed"""
8136  PRINT USING "6X,""2,,,5 Longer line - dash"""
8140  INPUT Ipn
8144  PRINTER IS 705
8148  BEEP
8152  INPUT "SELECT (0=LIN,1=LOG(X,Y))",Ilog
8156  Iprnt=1
8160  CALL Poly
8164  IF Ifn=0 THEN
8168  BEEP
8172  INPUT "ENTER NUMBER OF FILES TO JOIN?",Njoin
8176  END IF
```

```
8180  Ijoin=0
8184  IF Ifn<Njoin THEN Ijoin=1
8188  IF Ifn=0 OR Ijoin=1 THEN
8192  FOR Ij=0 TO 3
8196  Bs(Ij)=Bs(Ij)+B(Ij)
8200  NEXT Ij
8204  Ifn=Ifn+1
8208  END IF
8212  IF Njoin=Ifn THEN
8216  FOR Ij=0 TO 3
8220  B(Ij)=Bs(Ij)/Njoin
8224  Bs(Ij)=0
8228  NEXT Ij
8232  Ifn=0
8236  ELSE
8240  GOTO 7656
8244  END IF
8248  BEEP
8252  INPUT "ENTER Y LOWER AND UPPER LIMITS",Yll,Yul
8256  FOR Xx=0 TO Cx STEP Cx/200
8260  Xa=Xmin*10^Xx
8264  IF Xa<Xll OR Xa>Xul THEN 8372
8268  Icn=Icn+1
8272  Pu=0
8276  IF Ipn=1 THEN Idf=Icn MOD 2
8280  IF Ipn=2 THEN Idf=Icn MOD 4
8284  IF Ipn=3 THEN Idf=Icn MOD 8
8288  IF Ipn=4 THEN Idf=Icn MOD 16
8292  IF Ipn=5 THEN Idf=Icn MOD 28
8296  IF Idf=1 THEN Pu=1
8300  IF Opo=0 THEN Ya=FNPoly(Xa)
8304  IF Opo=2 AND Ilog=0 THEN Ya=Xa/FNPoly(Xa)
8308  IF Opo=2 AND Ilog=1 THEN Ya=FNPoly(Xa)
8312  IF Opo=1 THEN Ya=FNPoly(Xa)
8316  IF Ya<Ymin THEN 8372
8320  IF Ya<Yll OR Ya>Yul THEN 8372
8324  IF Iun=1 THEN
8328  IF Opo<2 THEN Xa=Xa*1.8
8332  IF Opo>0 THEN Ya=Ya*.1761
8336  IF Opo=0 THEN Ya=Ya*.317
8340  IF Opo=2 THEN Xa=Xa*.317
8344  END IF
8348  Y=LGT(Ya/Ymin)*Sfy
8352  X=LGT(Xa/Xmin)*Sfx
8356  IF Y<0 THEN Y=0
8360  IF Y>100 THEN GOTO 8372
8364  IF Pu=0 THEN PRINT "PA",X,Y,"PD"
8368  IF Pu=1 THEN PRINT "PA",X,Y,"PU"
8372  NEXT Xx
8376  PRINT "PU"
8380  GOTO 7656
8384  END IF
8388  BEEP
8392  INPUT "WANT TO PLOT REILLY'S DATA? (1=Y,0=N)",Irly
8396  IF Opo=0 OR Opo=1 THEN
8400  Xll=3
8404  Xul=20
8408  END IF
8412  IF Opo=2 THEN
8416  Xll=10000
```

```
8420   Xul=100000
8424   END IF
8428   IF Irly=1 THEN
8432   Yll=20
8436   Yul=70
8440   BEEP
8444   INPUT "ENTER LOWER AND UPPER Y-LIMITS FOR PLOTTING",Yll,Yul
8448   FOR Xx=0 TO Cx STEP Cx/200
8452   Xa=Xmin*10^Xx
8456   IF Xa<Xll OR Xa>Xul THEN 8508
8460   X1=LOG(Xa)
8464   IF Opo=0 THEN Y1=-2.5402837E-1+X1*(4.9720151-X1*2.5134787E-1)
8468   IF Opo=1 THEN Y1=-2.5402837E-1+X1*(3.9720151-X1*2.5134787E-1)
8472   IF Opo=2 THEN Y1=-3.7073801E-1+X1*(8.7259190E-1-X1*6.8826842E-3)
8476   Ya=EXP(Y1)
8480   Y=LGT(Ya/Ymin)*Sfy
8484   X=LGT(Xa/Xmin)*Sfx
8488   Ipu=0
8492   IF Y<Yll THEN Ipu=1
8496   IF Y>Yul THEN GOTO 8508
8500   IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
8504   IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
8508   NEXT Xx
8512   PRINT "PU"
8516   END IF
8520   BEEP
8524   INPUT "WANT TO PLOT ROHSENOW CORRELATION? (1=Y,0=N)",Irohs
8528   IF Irohs=1 THEN
8532   Yll=15
8536   Yul=80
8540   BEEP
8544   INPUT "ENTER Tsat (Deg C)",Tsat
8548   Csf=.0040
8552   BEEP
8556   INPUT "ENTER Csf (DEF=0.004)",Csf
8560   Tf=Tsat+2
8564   FOR Xx=0 TO Cx STEP Cx/200
8568   Xa=Xmin*10^Xx
8572   IF Xa<Xll OR Xa>Xul THEN 8684
8576   X1=LOG(Xa)
8580   IF Opo<2 THEN Tf=Tsat+Xa/2
8584   Rho=FNRho(Tf)
8588   K=FNK(Tf)
8592   Mu=FNMu(Tf)
8596   Cp=FNCp(Tf)
8600   Hfg=FNHfg(Tsat)
8604   Ni=Mu/Rho
8608   Pr=Cp*Mu/K
8612   Omega=Csf*Hfg/Cp*((.014/(9.81*Rho))^.5/(Mu*Hfg))^(1./3)*Pr^1.7
8616   IF Opo=0 THEN Ya=(Xa/Omega)^3
8620   IF Opo=1 THEN Ya=(Xa/Omega)^3/Xa
8624   IF Opo=2 THEN Ya=Xa^(2./3)/Omega
8628   IF Opo=2 THEN
8632   Tfc=Tsat+Xa/Ya*.5
8636   IF ABS(Tf-Tfc)>.01 THEN
8640   Tf=(Tf+Tfc)*.5
8644   GOTO 8584
8648   END IF
8652   END IF
8656   Y=LGT(Ya/Ymin)*Sfy
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```
8660   X=LGT(Xa/Xmin)*Sfx
8664   Ipu=0
8668   IF Y<Yll THEN Ipu=1
8672   IF Y>Yul THEN 8684
8676   IF Ipu=0 THEN PRINT "PA",X,Y,"PD"
8680   IF Ipu=1 THEN PRINT "PA",X,Y,"PU"
8684   NEXT Xx
8688   PRINT "PU"
8692   END IF
8696   BEEP
8700   INPUT "WANT TO QUIT (1=Y,0=N)",Iqt
8704   IF Iqt=1 THEN 8712
8708   GOTO 7636
8712   PRINT "PU PA 0,0 SP0"
8716   SUBEND
8720   SUB Symb(X,Y,Sym,Icl,Kj)
8724   IF Sym>3 THEN PRINT "SM"
8728   IF Sym<4 THEN PRINT "SR 1.4,2.4"
8732   Yad=0
8736   IF Kj=1 THEN Yad=.8
8740   IF Icl=0 THEN
8744   PRINT "PA",X,Y+Yad,""
8748   ELSE
8752   PRINT "PA",X,Y+Yad,"PD"
8756   END IF
8760   IF Sym>3 THEN PRINT "SR 1.2,1.6"
8764   IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,8,4,0;"
8768   IF Sym=5 THEN PRINT "UC3,0,99,-3,-6,-3,6,3,6,3,-6;"
8772   IF Sym=6 THEN PRINT "UC0,5.3,99,3,-8,-6,0,3,8;"
8776   IF Sym=7 THEN PRINT "UC0,-5.3,99,-3,8,6,0,-3,-8;"
8780   IF Kj=1 THEN PRINT "SM;PR 0,-.8"
8784   SUBEND
8788   SUB Purg
8792   BEEP
8796   INPUT "ENTER FILE NAME TO BE DELETED",File$
8800   PURGE File$
8804   GOTO 8792
8808   SUBEND
8812   SUB Tdcn
8816   COM /Cc/ C(7),Ical
8820   DIM Emf(1)
8824   DATA 0.10086091,25727.94369,-767345.8295,78025595.81
8828   DATA -9247486589,6.97688E+11,-2.66192E+13,3.94078E+14
8832   READ C(*)
8836   BEEP
8840   INPUT "GIVE A NAME FOR FILE TO BE CREATED",File$
8844   BEEP
8848   INPUT "SELECT TUBE (0=WH,1=HF,2=WT)",Itt
8852   BEEP
8856   INPUT "SELECT THERMOCOUPLE TYPE (0=NEW,1=OLD)",Ical
8860   IF Itt<2 THEN Di=.0127
8864   CREATE BDAT File$,4
8868   ASSIGN @File TO File$
8872   OUTPUT @File;Itt
8876   J=0
8880   BEEP
8884   OUTPUT 709;"TIMEDATE"
8888   ENTER 709;Dt
8900   PRINTER IS 1
8904   PRINT
```

```
8908  PRINT "          Month, date and time: ";DATE$(Dt),TIME$(Dt)
8912  PRINT
8916  PRINT USING "10X,"" Fms       Tin       Tev      Vw^2       Tdrop"""
8920  IF K=0 THEN
8924  PRINTER IS 701
8928  PRINT
8932  PRINT "          Month, date and time: ";DATE$(Dt),TIME$(Dt)
8936  IF Itt=0 THEN PRINT USING "10X,""Tube Type:           Wieland Smooth"""
8940  IF Itt=1 THEN PRINT USING "10X,""Tube Type:           High Flux"""
8944  IF Itt=2 THEN PRINT USING "10X,""Tube Type:           Turbo-B"""
8948  PRINT
8952  PRINT USING "10X,"" Fms       Tin       Tev      Vw^2       Tdrop"""
8956  PRINTER IS 1
8960  K=1
8964  END IF
8968  BEEP
8972  INPUT "ENTER FLOWMETER READING",Fms
8976  OUTPUT 709;"AR AF0 AL4 VR1"
8980  FOR L=0 TO 4
8984  OUTPUT 709;"AS SA"
8988  IF L>0 AND L<4 THEN 9020
8992  S=0
8996  FOR I=0 TO 9
9000  ENTER 709;E
9004  S=S+E
9008  NEXT I
9012  IF L=0 THEN Emf(0)=ABS(S/10)
9016  IF L=4 THEN Emf(1)=ABS(S/10)
9020  NEXT L
9024  OUTPUT 709;"AR AF20 AL20 VR1"
9028  OUTPUT 709;"AS SA"
9032  Etp=0
9036  FOR I=0 TO 9
9040  ENTER 709;Et
9044  Etp=Etp+Et
9048  NEXT I
9052  Etp=Etp/10
9056  Tin=FNTvsv(Emf(1))
9060  Tev=FNTvsv(Emf(0))
9064  Grad=37.9853+.104388*Tin
9068  Mdot=3.9657E-3+Fms*(3.61955E-3-Fms*(8.82006E-6-Fms*(1.23688E-7-Fms*4.31897
E-10)))
9072  Vw=Mdot/(1000*PI*Di^2)*4
9076  Tdrop=Etp*1.E+6/(10*Grad)
9080  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
9084  BEEP
9088  INPUT "WANT TO ACCEPT THIS DATA SET? (1=Y,0=N)",Ok
9092  J=J+1
9096  IF Ok=0 THEN
9100  J=J-1
9104  GOTO 8968
9108  ELSE
9112  OUTPUT @File;Fms,Emf(*),Etp
9116  PRINTER IS 701
9120  PRINT USING "10X,3(DD.DD,4X),1X,Z.DD,4X,MZ.4D";Fms,Tin,Tev,Vw^2,Tdrop
9124  PRINTER IS 1
9128  BEEP
9132  INPUT "WILL THERE BE ANOTHER DATA SET? (1=Y,0=N)",Go_on
9136  IF Go_on=1 THEN 8968
9140  END IF
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```
9144  ASSIGN @File TO *
9148  PRINTER IS 701
9152  PRINT
9156  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";J,F
ile$
9160  PRINTER IS 1
9164  SUBEND
9168  SUB Uoprt
9172  PRINTER IS 1
9176  BEEP
9180  INPUT "Enter Uo File Name",File$
9184  BEEP
9188  INPUT "Number of Data Runs",Nrun
9192  INPUT "Do You Want a Plot File?(1=Y,0=N)",Iplot
9196  BEEP
9200  IF Iplot=1 THEN
9204  INPUT "Give Plot File Name",P_file$
9208  CREATE BDAT P_file$,4
9212  ASSIGN @Plot TO P_file$
9216  END IF
9220  PRINTER IS 701
9224  PRINT
9228  PRINT
9232  PRINT USING "10X,""    Water Vel         Uo"""
9236  ASSIGN @File TO File$
9240  IF Iplot=1 THEN ASSIGN @File1 TO P_file$
9244  FOR I=1 TO Nrun
9248  ENTER @File;Vw,Uo
9252  IF Iplot=1 THEN OUTPUT @File1;Vw,Uo
9256  PRINT USING "15X,D.DD,6X,MZ.3DE";Vw,Uo
9260  NEXT I
9264  ASSIGN @File TO *
9268  ASSIGN @File1 TO *
9272  PRINT USING "10X,""NOTE: "",ZZ,"" data sets are stored in file "",15A";Nru
n,File$
9276  IF Iplot=1 THEN
9280  PRINT USING "10X,""NOTE: "",ZZ,"" X-Y Pairs are stored in file "",15A";Nru
n,P_file$
9284  END IF
9288  PRINTER IS 1
9292  SUBEND
9296  SUB Select
9300  COM /Idp/ Idp
9304  BEEP
9308  PRINTER IS 1
9312  PRINT USING "4X,""Select option:"""
9316  PRINT USING "6X,"" 0 Taking data or re-processing previous data"""
9320  PRINT USING "6X,"" 1 Plotting data on Log-Log """
9324  PRINT USING "6X,"" 2 Plotting data on Linear"""
9328  PRINT USING "6X,"" 3 Make cross-plot coefft file"""
9332  PRINT USING "6X,"" 4 Re-circulate water"""
9336  PRINT USING "6X,"" 5 Purge"""
9340  PRINT USING "6X,"" 6 T-Drop correction"""
9344  PRINT USING "6X,"" 7 Print Uo File"""
9345  PRINT USING "6X,"" 8 Modify X-Y file"""
9346  PRINT USING "6X,"" 9 Move"""
9347  PRINT USING "6X,""10 Comb/Fixup"""
9348  INPUT Idp
9352  IF Idp=0 THEN CALL Main
9356  IF Idp=1 THEN CALL Plot
```

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```
9360  IF Idp=2 THEN CALL Plin
9364  IF Idp=3 THEN CALL Coef
9368  IF Idp=4 THEN CALL Main
9372  IF Idp=5 THEN CALL Purg
9376  IF Idp=6 THEN CALL Tdcn
9380  IF Idp=7 THEN CALL Uoprt
9381  IF Idp=8 THEN CALL Xymod
9382  IF Idp=9 THEN CALL Move
9383  IF Idp=10 THEN CALL Comb
9385  SUBEND
9394  SUB Xymod
9434  PRINTER IS 1
9444  BEEP
9454  INPUT "ENTER FILE NAME",File$
9464  ASSIGN @File1 TO File$
9474  BEEP
9484  INPUT "ENTER NUMBER OF X-Y PAIRS",Np
9494  BEEP
9504  INPUT "ENTER NEW FILE NAME",File2$
9514  CREATE BDAT File2$,5
9524  ASSIGN @File2 TO File2$
9534  BEEP
9544  INPUT "ENTER NUMBER OF X-Y PAIRS TO BE DELETED",Ndel
9554  IF Ndel=0 THEN 9594
9564  FOR I=1 TO Ndel
9574  BEEP
9584  INPUT "ENTER DATA SET NUMBER TO BE DELETED",Nd(I)
9594  NEXT I
9604  FOR J=1 TO Np
9614  ENTER @File1;X,Y
9624  FOR I=1 TO Ndel
9634  IF Nd(I)=J THEN 9674
9644  NEXT I
9654  OUTPUT @File2;X,Y
9664  PRINT J,X,Y
9674  NEXT J
9675  PRINTER IS 701
9684  ASSIGN @File1 TO *
9694  ASSIGN @File2 TO *
9704  SUBEND
9714  SUB Move
9718! FILE NAME: MOVE
9722!
9726  DIM Bop(66),A(66),B(66),C(66),D(66),E(66),F(66),G(66),H(66),J(66),K(66),L(
66),M(66)
9730  DIM Told(66),N(66),Vr(66),Ir(66)
9734  BEEP
9738  INPUT "OLD FILE TO MOVE",D2_file$
9742  ASSIGN @File2 TO D2_file$
9746  ENTER @File2;Nrun,Dt,Ldtc1,Ldtc2,Itt
9750  FOR I=1 TO Nrun
9754  ENTER @File2;Bop(I),Told(I)
9758  ENTER @File2;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),N
(I)
9762  ENTER @File2;Vr(I),Ir(I)
9766  NEXT I
9770  ASSIGN @File2 TO *
9774  BEEP
9778  INPUT "SHIFT DISK AND HIT CONTINUE",Ok
9782  BEEP
```

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```
9786   INPUT "INPUT BDAT SIZE",Size
9790   CREATE BDAT D2_file$,Size
9794   ASSIGN @File1 TO D2_file$
9798   OUTPUT @File1;Nrun,Dt,Ldtc1,Ldtc2,Itt
9802   FOR I=1 TO Nrun
9806   OUTPUT @File1;Bop(I),Told(I)
9810   OUTPUT @File1;A(I),B(I),C(I),D(I),E(I),F(I),G(I),H(I),J(I),K(I),L(I),M(I),
N(I)
9814   OUTPUT @File1;Vr(I),Ir(I)
9818   NEXT I
9822   ASSIGN @File1 TO *
9826!  RENAME "TEST" TO D2_file$
9830   BEEP 2000,.2
9834   BEEP 4000,.2
9838   BEEP 4000,.2
9842   PRINT "DATA FILE MOVED"
9846   SUBEND
9874   SUB Comb
9878!  FILE NAME: COMB
9882!
9886   DIM Emf(12)
9890   BEEP
9894   INPUT "OLD FILE TO FIXUP",D2_file$
9898   ASSIGN @File2 TO D2_file$
9902   D1_file$="TEST"
9906   CREATE BDAT D1_file$,20
9910   ASSIGN @File1 TO D1_file$
9914   ENTER @File2;Nrun,Dt,Ldtc1,Ldtc2,Itt
9915   Nrunm=20
9918   IF K=0 THEN OUTPUT @File1;Nrunm,Dt,Ldtc1,Ldtc2,Itt
9922   FOR I=1 TO Nrun
9926   ENTER @File2;Bop,Told,Emf(*),Vr,Ir
9930   OUTPUT @File1;Bop,Told,Emf(*),Vr,Ir
9934   NEXT I
9938   ASSIGN @File2 TO *
9942!  RENAME "TEST" TO D2_file$
9946   BEEP 2000,.2
9950   BEEP 4000,.2
9954   BEEP 4000,.2
9958   BEEP
9962   INPUT "WANT TO ADD ANOTHER FILE (1=Y,0=N)?",Oke
9966   IF Oke=1 THEN
9970   K=1
9974   BEEP
9978   INPUT "GIVE NEW FILE NAME",Nfile$
9982   ASSIGN @File2 TO Nfile$
9986   GOTO 9914
9990   END IF
9994   ASSIGN @File2 TO *
9998   SUBEND
```

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